

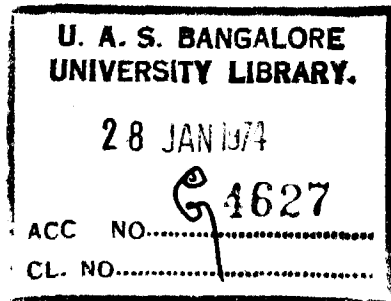
# CROPS AND WEATHER IN INDIA

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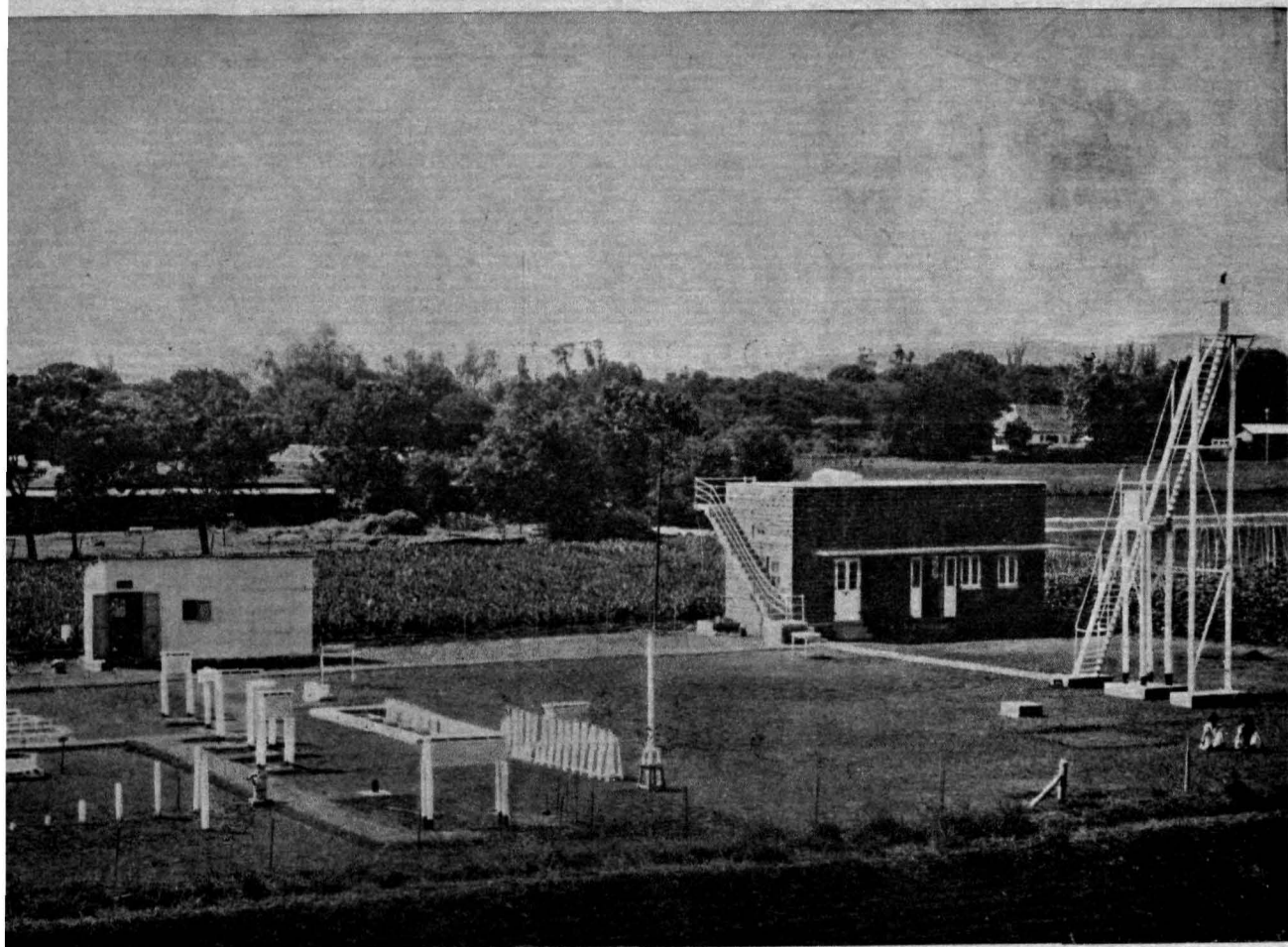
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# *CROPS AND WEATHER IN INDIA*



A view of the Central Agricultural Meteorological Observatory, Poona

## PREFACE

Agriculture has many 'Controls'. Of all these 'Weather' is a major control. The scientific study of the influence of various weather factors on the growth and yield of crops is of comparatively recent origin, less than two decades old in most countries. The subject is in the developing stage at present but even so, it will take several chapters to do full justice to the various aspects of this new science of Agricultural Meteorology. All we can attempt within the scope of this monograph is to sketch in bare outline the scope and implications of the present fact-finding stage in order to impress upon the student of agriculture the importance of weather science and weather forecasts to agriculture.

As far as possible, we shall confine ourselves to the results obtained so far by the workers on agricultural meteorology in India.

It will be useful at this stage to indicate how the treatment of the subject will proceed in the succeeding pages.

In Chapter I, we shall discuss the bearings of long term climatic variations, rainfall dependability, etc., on Indian agriculture, the frequencies of various types of weather abnormalities and the like and end up with a description of the new Weather Service for agriculture inaugurated by the India Meteorological Department.

In Chapter II, the basic problems connected with the disposal of (a) solar radiation and (b) the moisture received at the ground surface in the shape of rainfall or irrigation, will be outlined. The important subject of micro-climatology, techniques of studying its basic features, methods of partial control of the micro-climate and other allied topics will also be discussed here.

Chapter III will deal with the techniques developed for recording systematic crop and weather observations according to a common plan—the 'Co-ordinated Crop Weather Scheme'—and indicate the urgency and importance of organising and maintaining this long term scheme which is so essential for the study of crop-weather relations on scientific lines.

As far as possible, to condense the descriptive matter, the aid of diagrams and tables will be resorted to.

In the present review we have had to take in a very wide range of topics which are likely to interest those dealing with Agriculture in India. The treatment of many of the topics has been necessarily terse or sketchy, but those who wish to know further may consult the numerous publications referred to.

The writer wishes to acknowledge here the uniformly enthusiastic support and encouragement he had received for many years from the Indian Council of Agricultural Research, the Indian Meteorological Department, the Indian Central Sugarcane and Cotton Committees and Agricultural Departments and Institutions in the States of India. The work on Agricultural Meteorology represents the sustained efforts of a team consisting of members of the staff and voluntary post graduate students and my grateful thanks are due to all the members of this team.

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It should not be imagined that the monsoon behaves as a steady phenomenon. If that were so, the rainfall would have been mainly orographic, *i.e.* to the windward side of the mountain barriers along the West Coast, the Arakkan mountains and the Himalayas. Fortunately, the monsoon currents pulsate with the series of eastern depressions originating or reviving over the head of the Bay of Bengal and moving in a westerly to north-westerly direction across North and Central India. These depressions occur at intervals during the monsoon season and during their passage divert the humid currents into the central and north-western tracts of the Sub-Continent thus bringing about a more equitable distribution of rainfall over the country. Fig. 3 shows the average wind currents in July when the monsoon is usually most vigorous. Besides the above variations in the intensity of the monsoon, there are also temporary breaks when rainfall tends to decrease in the plains and persists in the Himalayan tracts.

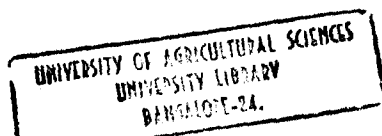
By mid-September the south-west monsoon rapidly withdraws from the country as what is termed the 'retreating monsoon'. This gradually leads to the north-easterly air currents assuming full sway over the Sub-Continent and the adjoining seas by January, as shown in Fig. 4. The north-east monsoon, as it is called, is associated with rainy weather over the southern parts of peninsular India, particularly over Tamilnad from November to the end of January.

Besides the setting in of the monsoon early in June, its extension into India during June and July, and finally its retreat southwards in September and October, we have also to consider the other major phenomena like cyclonic storms and depressions.

*Eastern Depressions.* The fluctuations in the intensity of the monsoon itself are to a very large extent associated with a series of depressions which mostly originate (or, when they are coming from farther east, strengthen) at the head of the Bay of Bengal and travel in a north-westerly direction across the country towards North-west India, causing heavy rainfall along their track. The frequency of such depressions is 3 or 4 per month during the monsoon months (June to September). In some years the frequency of these depressions comes down very much and then the monsoon rainfall tends to become 'orographical' (*i.e.* confined to the hills and mountains); this brings out the importance of the depressions for securing proper spatial distribution of the rainfall over the plains of North and Central India; in years of few depressions, droughts occur in the interior regions of the country, in the north-west and central parts of India.

*Western Depressions.* During the period November to May, a series of western depressions enter India through the North-West Frontier and Baluchistan and move eastwards across North India towards North-east India (Assam-Bengal). These depressions cause cloudy weather and light rains in the plains with snowfall in the Himalayas and are followed by cold waves. The frequency of these western depressions is, on an average, two in November, four to five per month during December to April and about two in May.

*Cyclonic Storms.* The more severe cyclonic storms usually form in the Bay of Bengal and in the Arabian Sea in the transition periods April to June and October to December. They enter inland and cause considerable precipitation and damage due to high winds and occasionally, tidal waves, in the coastal tracts. The mode of occurrence of these storms and depressions and their favourite tracks have been discussed at length in the publications of the India Meteorological Department. On an average one or two severe cyclones may be expected in the pre-monsoon period, and two or three in the post-monsoon period.



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*South-West Monsoon*

*Date of Establishment.* As is well known, the Indian farmer looks forward with great anxiety to the onset of the monsoon and prays for a timely and suitable distribution of rainfall during the season. Figs. 5 and 6 show the normal dates of onset and withdrawal of the monsoon in different parts of India. The actual dates of onset as well as the intensity and distribution in time and space of the monsoon precipitation vary from year to year. Table 2 gives the actual dates of establishment of the south-west monsoon in four areas along the west coast of the peninsula. It will be noticed that there is considerable variation not only in the dates of establishment but also in the speed with which the monsoon current moves from the Travancore-Cochin area to Kolaba in the north (near Bombay). Table 3 summarises the information given in Table 2.

As the major agricultural operations have to synchronise with the monsoon rains, the prediction of the date of establishment of the monsoon in different parts of the country and the spells of rain and of breaks during the season is of great importance to agriculture.

TABLE 2. DATE OF ESTABLISHMENT OF THE SOUTH-WEST MONSOON ALONG THE WEST COAST OF INDIA

Year	Travancore-Cochin		S. Kanara		Ratnagiri		Kolaba	
1891	May	27	June	3	June	19	June	21
1892	"	22	May	24	May	29	May	31
1893	"	22	June	4	June	10	June	10
1894	June	1	"	2	"	7	"	7
1895	"	8	"	12	"	14	"	15
1896	May	30	May	31	"	1	"	1
1897	"	30	June	5	"	7	"	7
1898	June	2	"	3	"	8	"	8
1899	May	23	"	7	"	9	"	10
1900	June	6	"	8	"	9	"	9
1901	"	1	"	4	"	7	"	7
1902	May	31	"	6	"	7	"	12
1903	June	8	"	11	"	12	"	12
1904	May	29	"	1	"	7	"	8
1905	June	6	"	8	"	9	"	10
1906	"	3	"	6	"	7	"	8
1907	May	31	"	5	"	11	"	11
1908	June	8	"	10	"	11	"	11
1909	"	1	"	2	"	3	"	3
1910	May	28	"	2	"	3	"	3
1911	June	1	"	2	"	4	"	4
1912	"	4	"	6	"	12	"	12
1913	May	24	"	1	"	6	"	7
1914	"	28	"	5	"	13	"	13
1915	June	3	"	12	"	17	"	18
1916	May	26	May	27	May	31	"	1
1917	"	26	"	29	June	4	"	5
1918	"	7	"	15	May	22	May	25
1919	"	16	"	26	June	4	June	6
1920	"	27	June	2	"	6	"	6
1921	"	1	"	3	"	10	"	12
1922	"	25	May	31	"	10	"	12
1923	"	4	June	11	"	12	"	13
1924	"	31	"	3	"	10	"	12

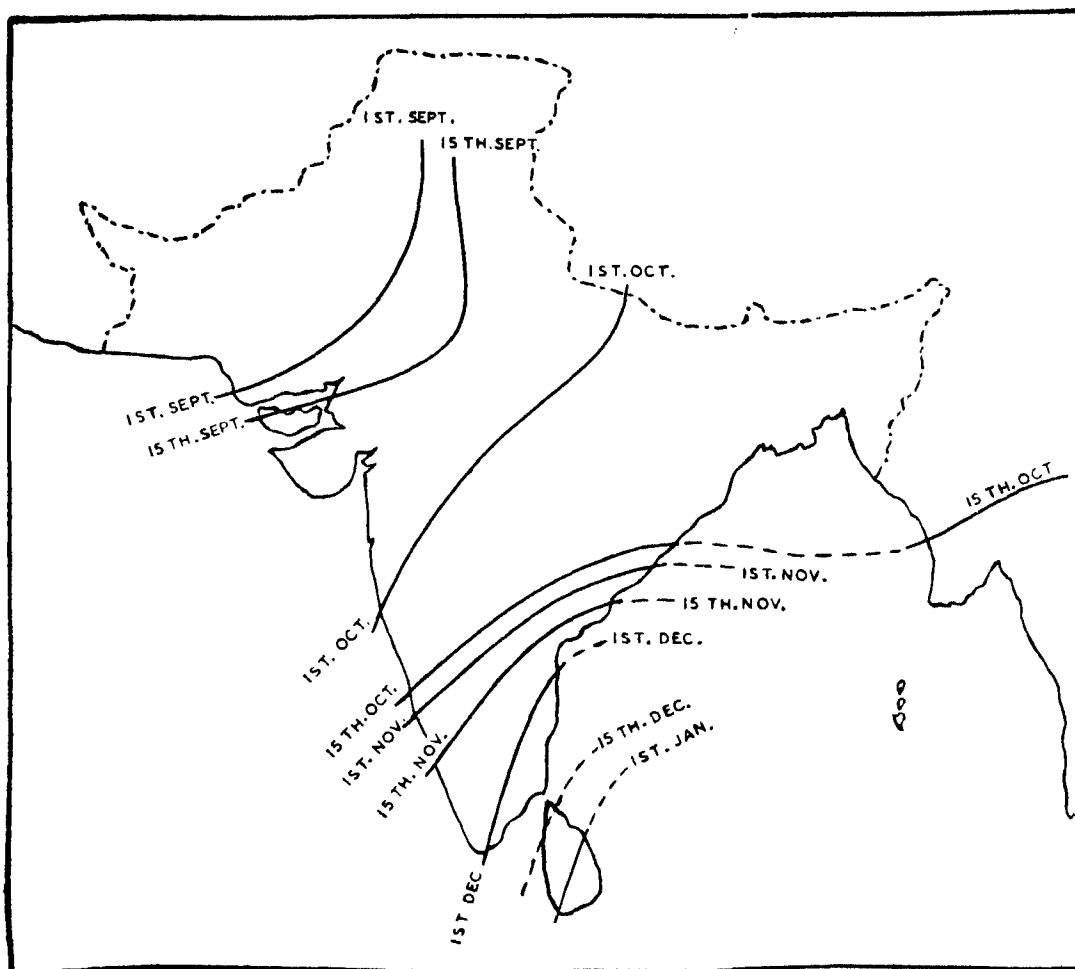


FIG. 6. Normal dates of withdrawal of the S. W. Monsoon

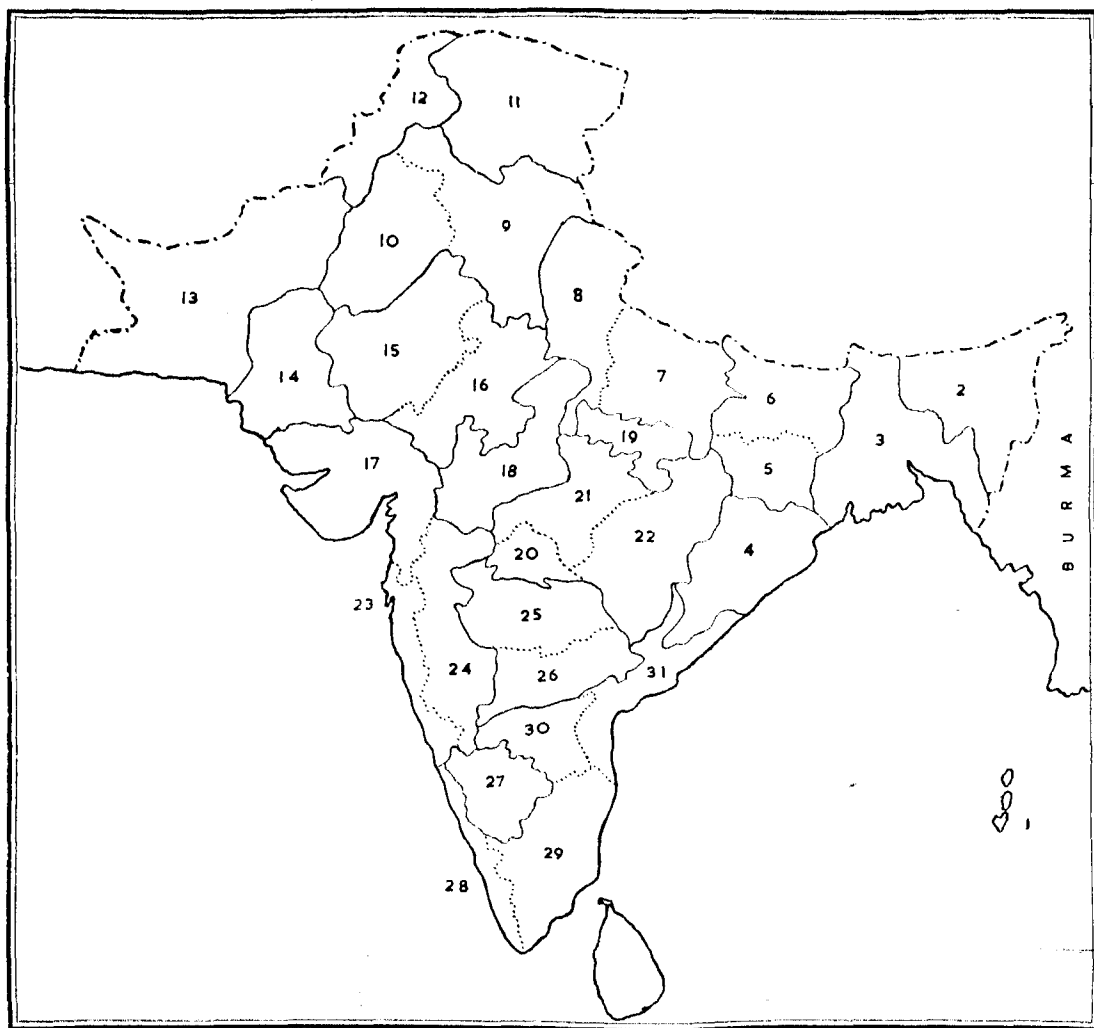


FIG. 7. Map of India showing rainfall sub-divisions

1. Bay islands 2. Assam 3. Bengal 4. Orissa 5. Chota Nagpur 6. Bihar 7. United Provinces, east 8. United Provinces, west 9. Punjab, east & north 10. Punjab, south-west 11. Kashmir 12. N. W. Frontier Province 13. Baluchistan 14. Sind 15. Rajputana, west 16. Rajputana, east 17. Gujarat 18. Central India, west 19. Central India, east 20. Berar 21. Central Provinces, west 22. Central Provinces, east 23. Konkan 24. Bombay, Deccan 25. Hyderabad, north 26. Hyderabad, south 27. Mysore 28. Malabar 29. Madras, south-east 30. Madras, Deccan 31. Madras, east-north.

TABLE 2. *Concluded.*

Year	Travancore-Cochin		S. Kanara		Ratnagiri		Kolaba	
1925	May	27	May	28	May	29	May	29
1926	"	28	June	5	June	9	June	10
1927	"	23	May	27	"	10	"	10
1928	"	31	"	31	"	5	"	7
1929	"	29	"	30	"	1	"	6
1930	"	21	June	7	"	8	"	9
1931	"	23	May	29	"	14	"	14
1932	"	14	June	2	"	3	"	3
1933	"	22	May	28	"	1	"	1
1934	June	6	June	6	"	10	"	10
1935	"	10	"	10	"	12	"	14
1936	May	20	May	22	May	29	"	1
1937	June	3	June	10	June	11	"	12
1938	"	1	"	2	"	2	"	4
1939	"	6	"	6	"	7	"	9
1940	"	7	"	13	"	16	"	18
1941	May	23	"	3	"	14	"	16
1942	June	4	"	8	"	12	"	13
1943	May	12	May	14	May	21	May	21
1944	"	29	"	30	June	9	June	10
1945					"	12	"	14

TABLE 3. DATE OF ESTABLISHMENT OF THE SOUTH-WEST MONSOON ALONG THE WEST COAST OF INDIA

Area	Mean date		Standard deviation (in days)	Earliest date		Latest date	
Travancore-Cochin	May	29	7.0	May	7	June	10
South Kanara	June	3	5.7	"	15	"	12
Ratnagiri	"	7	5.4	"	22	"	19
Kolaba	"	8	5.2	"	25	"	21

This problem has been extensively investigated by Ramdas and co-workers (143). The following prior world-weather factors are found to have some measure of influence on the subsequent 'date of establishment' of the south-west monsoon :

1. Rainfall in the Seychelles in the preceding April (positive).
2. Mean west winds over Agra (1 KM + 2 KM + 3 KM) during the first half of the preceding May (positive).
3. Darwin (Australia) pressure in the preceding April (positive).
4. Difference of pressure between Cochin and Jaipur during the preceding April (negative).
5. South Rhodesian rainfall during the preceding period, October to April (negative).
6. South Rhodesian rainfall during the preceding April (negative).

Forecasting formulae expressing departures from the normal of the date of establishment as simple linear functions of the departures of four or more of the above factors have been worked out for (a) the West Coast as a whole, (b) the northern half of the West Coast and (c) the southern half of the West Coast.

These formulae are now in course of trial over a few years. For a full discussion of this investigation a recent paper by Ramdas *et al.* (143), may be referred to. Further work for exploring the possibilities of predicting the 'date of withdrawal' and breaks during the South-west monsoon is in progress.

#### HOW THE SOUTH-WEST MONSOON HAS BEHAVED IN INDIA DURING THE PAST 75 YEARS, 1875 TO 1949—FREQUENCY OF FLOODS AND DROUGHTS

In dealing with future long-term planning of agriculture, irrigation works, etc. it is important to study the lessons of past meteorological history. We have reliable rainfall data in India for the past 75 years or so. Let us consider how many of the past monsoons were beneficial and how many were total or partial failures.

For this purpose we may first of all consider the total rainfall during the entire (South-west) monsoon season, June to September. If the deviation of the actual rainfall in a year in a sub-division (Fig. 7 shows the rainfall sub-divisions of the Indian sub-continent) is more than twice the mean deviation, that year may be defined as a year of flood or drought according as the departure is positive or negative respectively. Fig. 8 shows at a glance how the monsoon has behaved in the past 75 years in each of the 30 rainfall sub-divisions. In Fig. 8 the filled circle indicates a flood, the open circle drought and the blank spaces are years and sub-divisions with more or less normal monsoon rainfall.

Fig. 8 shows all the major abnormalities at a glance. Generally speaking, when a large number of years are considered, the number of floods and droughts tend to equalise. It is the areas with very low rainfall (e.g. Baluchistan, Sind, Rajputana, etc.) which experience the greatest number of abnormalities; on the other hand, in areas like the Konkan, Malabar, Bengal, etc. where the monsoon rainfall is above 40", the number of abnormalities comes down very much. These features are also clear from Table 4.

Considering the experience during each of the years 1875 to 1949, the years 1877, 1899 and 1918 stand out most prominently as years of general drought. Such countrywide droughts occur once in about twenty years. It will be recalled that these were actually years of great famine and distress. In the year 1920, there was a partial drought, only the north-west and the central parts of the country being affected. The years of general flood are 1878, 1892 and 1917. In two instances at least (1877, 1878 and 1917, 1918) floods and droughts occurred in consequent years. There is no regularity in time in the distribution of floods and droughts. The chances of one drought being succeeded by another or a flood year being succeeded by another in any particular sub-division appear to be small. Areas of drought and flood often tend to be associated into centres of defective or excessive rainfall in the years in which they do occur. Much useful information about the weather risk due to incidence of floods and droughts in different parts of India can be obtained from Fig. 8. Diagrams such as Fig. 8 in respect of the districts of each rainfall sub-division in India will be of very great interest to the local administrations, agricultural and irrigation officers, etc. while planning their long-term developments.



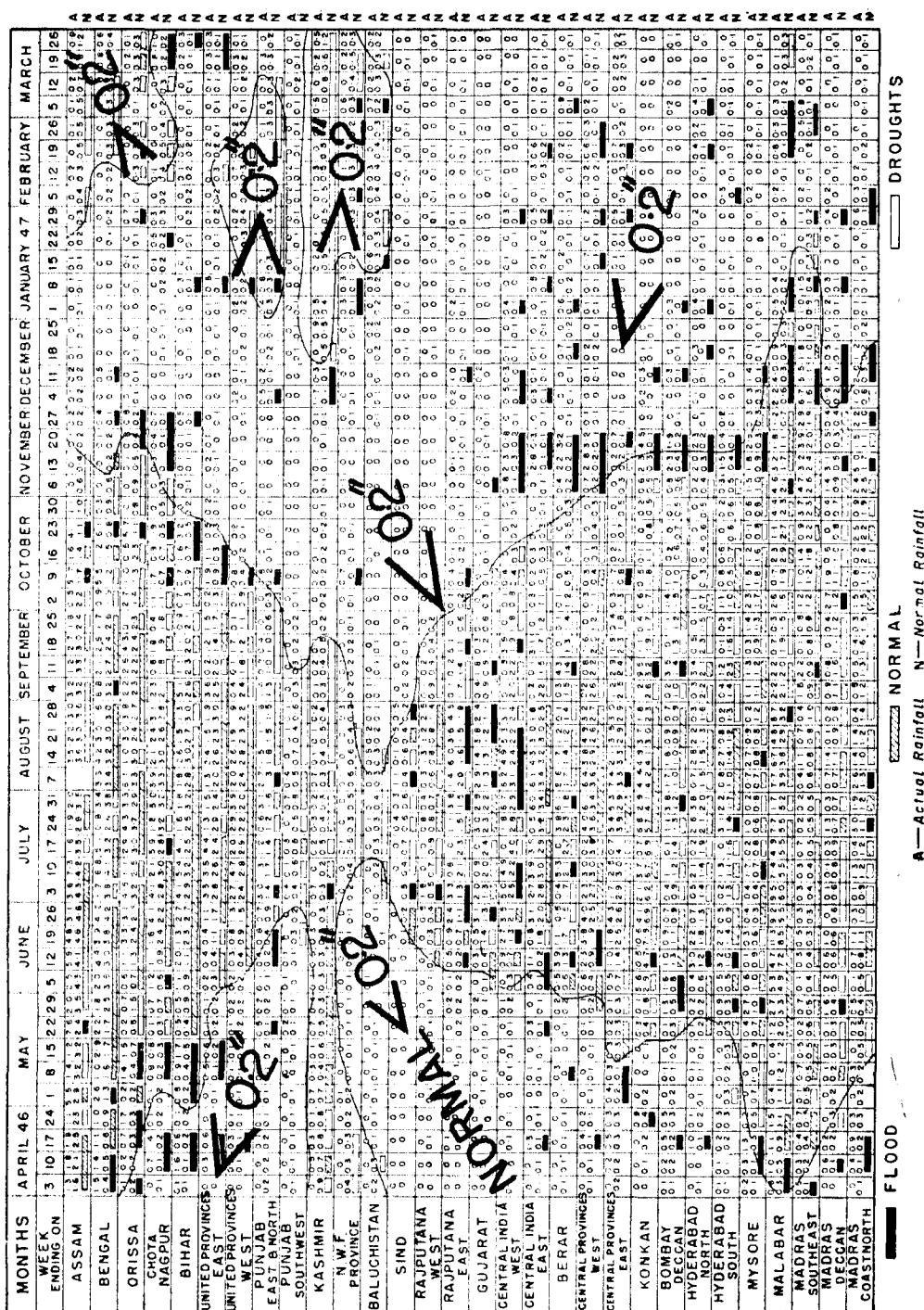


FIG. 9. Rainfall of India week by week (1946-47)

TABLE 4. ABNORMALITIES DURING 100 YEARS

Name of Sub-division	Normal rainfall (June to September) (inches)	Limit for deviation for abnormality (inches)	Number of abnormalities in 100 years		
			Floods	Droughts	Total
Assam	64.3	10.0	6	4	10
Bengal	56.0	10.0	3	4	7
Orissa	44.5	10.0	10	3	13
Chota Nagpur	42.7	10.0	1	3	4
Bihar	41.0	10.0	10	11	21
U. P. East	34.4	10.0	13	10	23
U. P. West	33.0	10.0	6	11	17
Punjab E. & N.	18.2	6.0	14	11	25
Punjab S. W.	6.6	4.0	11	4	15
Kashmir	22.2	6.0	4	13	17
N. W. F. P.	8.7	4.0	13	4	17
Baluchistan	1.9	1.2	17	17	34
Sind	5.3	4.0	16	11	27
Rajputana W.	11.7	6.0	11	10	21
Rajputana E.	22.7	10.0	9	6	15
Gujarat	31.5	14.0	9	9	18
Central India W.	31.6	10.0	10	4	14
Central India E.	35.1	15.0	4	6	10
Berar	28.1	10.0	10	6	16
C. P. West	41.0	10.0	11	10	21
C. P. East	46.4	10.0	9	6	15
Konkan	102.5	28.0	3	9	12
Bombay Deccan	24.4	7.0	6	6	12
Hyderabad N.	29.5	10.0	9	6	15
Hyderabad S.	23.4	9.0	10	7	17
Mysore	22.3	8.0	4	1	5
Malabar	71.5	20.0	7	4	11
Madras S. E.	12.0	4.0	7	7	14
Madras Deccan	15.3	7.0	7	6	13
Madras Coast North	25.0	7.0	10	1	11
		Mean➤	9	7	16

## RAINFALL OF INDIA, WEEK BY WEEK FOR EACH YEAR

We may turn to the problem of rainfall 'distribution' week by week. For this purpose we use the rainfall data published regularly in the weekly weather reports of the India Meteorological Department. The method of presenting the actual and the normal weekly rainfall week by week, for all the 30 sub-divisions of India in a single chart (88) is illustrated by Fig. 9 which refers to the years 1946-47. Against each sub-division for each week two entries are made. The upper figure gives the actual while the lower gives the normal weekly rainfall. For marking out the abnormalities, weeks with the actual rainfall equal to or less than half the normal have been defined as droughts; weeks with the actual rainfall equal to or more than twice the normal have been defined as floods. The incidence of droughts and floods as defined above is shown in Fig. 9 by under-lining with filled and open

bars respectively. The normal weeks when the rainfall was within the above limits (*i.e.* more than half and less than twice the normal) are underlined with hatched bars. The areas in the diagram where the normal weekly rainfall is less than 0.2" have been demarcated by the continuous thin lines. These represent the dry season when drought is the rule and only floods, if any, need be indicated.

The ideal year will be one in which there are no droughts or floods. Successful crop production depends not only on the total seasonal rainfall, but also on the proper distribution of the rainfall in time and space. Even a sub-normal rainfall may, if well distributed, produce a good yield. The incidence of some spells of drought and of flood is to be expected in most years. In many years only short spells of drought and flood alternate without materially affecting the total rainfall of the season. Once in about 5, 10 or 20 years, however, depending on the area concerned, the drought or flood extends over a number of consecutive weeks; such prolonged spells, particularly at the critical stages of crops, cause widespread damage.

It will be seen from Fig. 9 that, on the whole, the year 1946-47 has not been quite favourable. The number of abnormal spells, *i.e.* floods and droughts indicates that the distribution of the monsoon rainfall was far from ideal although there was no prolonged spell of flood or drought over any large part of the country. But an outstanding feature of this year was the unseasonable rain during the winter (November 1946 to February 1947) in the Central parts of the country. In these parts consisting of Central India, the Central Provinces and Berar, Bombay and Hyderabad, there was absence of the seasonal cold weather during winter and the incidence of wet and cloudy weather, as will be seen from the large number of floods. This comparatively warm and cloudy wet weather provided conditions most favourable for the incidence of 'rust' disease of wheat.

Charts like Fig. 9 have been prepared for a series of 40 years (1908 to 1948). These charts reveal that the method of presentation of the weekly rainfall data brings out in a striking manner all the major abnormalities which are likely to affect agricultural and related activities adversely.

When we wish to see at a glance the rainfall abnormalities of a particular rainfall subdivision all the 40 years (91), the information in the above 40 charts can be presented in the manner shown in Figs. 10 to 13, as typical examples.

Fig. 10 shows how liable Gujarat is to long spells of abnormal rainfall from June to September which constitutes its wet season. Long spells of floods had occurred more than twice in the rainy season (which normally covers 17 weeks only) or 4 weeks' spells continuously in 1917, 1926 and 1932. Coming to droughts these had occurred for 7 weeks or more continuously in 1910, 1911, 1915, 1918, 1925 and 1948 (once in five years on an average).

Fig. 11 refers to Madhya Pradesh (West). The wet season lasts longer than in Gujarat, *viz.* for 23 weeks (last week of May to end of October). This area has a more dependable rainfall than Gujarat. Although droughts of more than 5 weeks' duration have occurred 9 times in 40 years, those exceeding 6 weeks continuously have occurred only twice (1912 and 1939) in the same period. 'Floods' lasting for 4 weeks continuously have also occurred in three years *i.e.* 1917, 1931 and 1936. It is re-assuring to find the long spells of 'normal' rainfall which occur in this area.

From Fig. 12 it will be seen that in Malabar the wet season extends without break from April to December and includes both the south-west monsoon and the significant

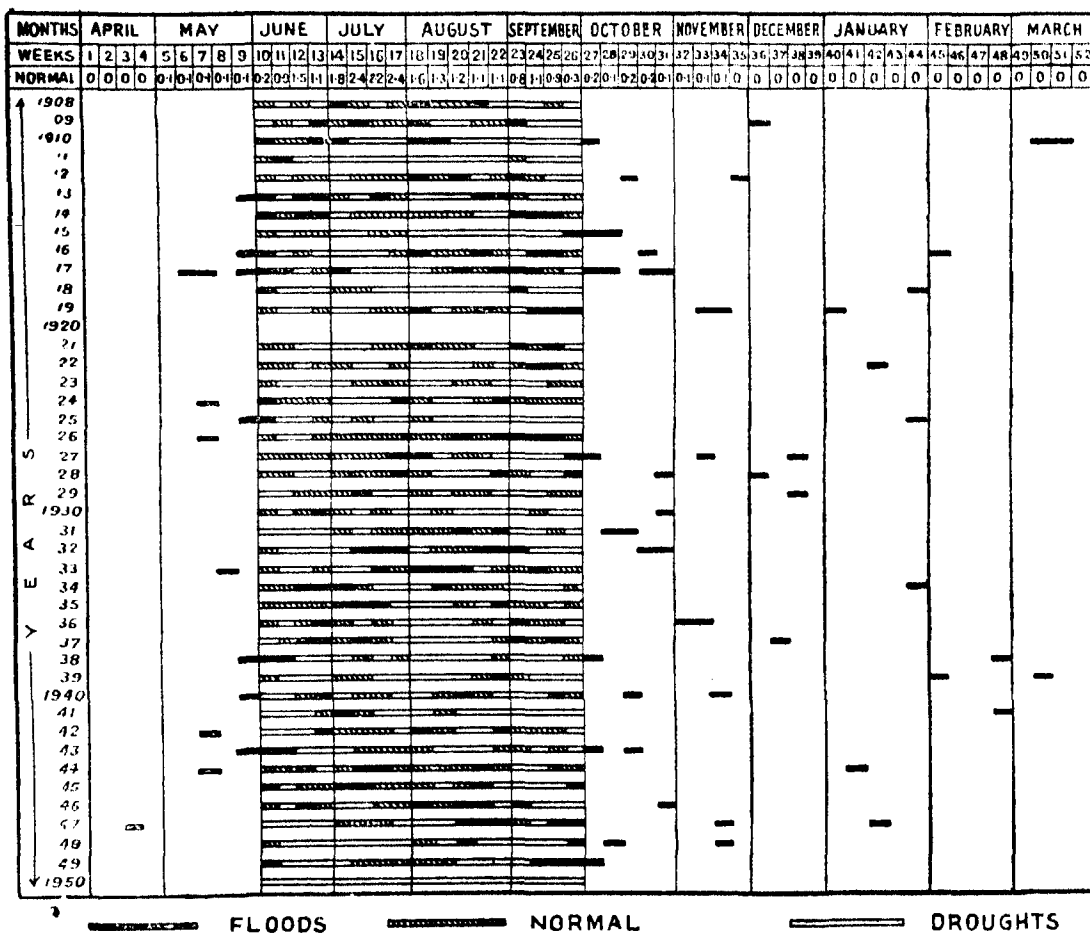


FIG. 10. Rainfall of Gujarat week by week



FIG. 11. Rainfall of Madhya Pradesh (West) week by week

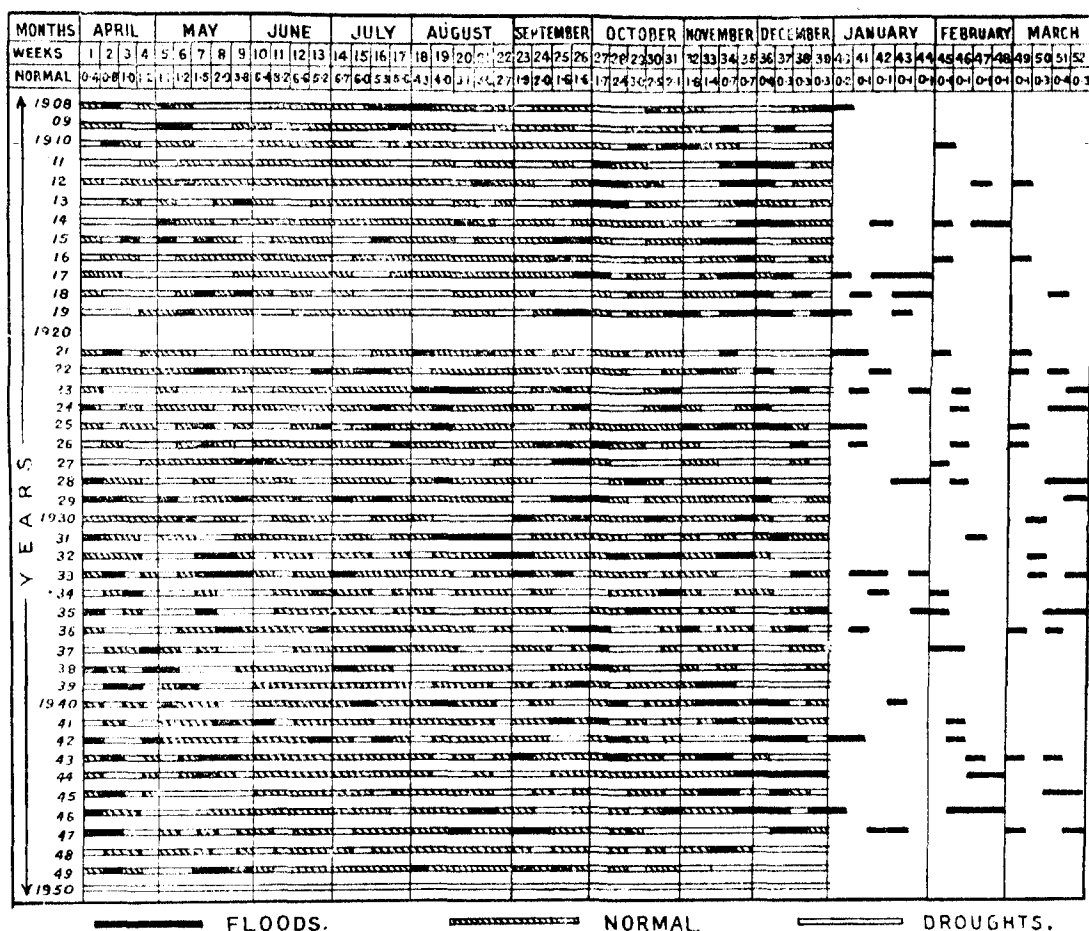


FIG. 12. Rainfall of Malabar week by week

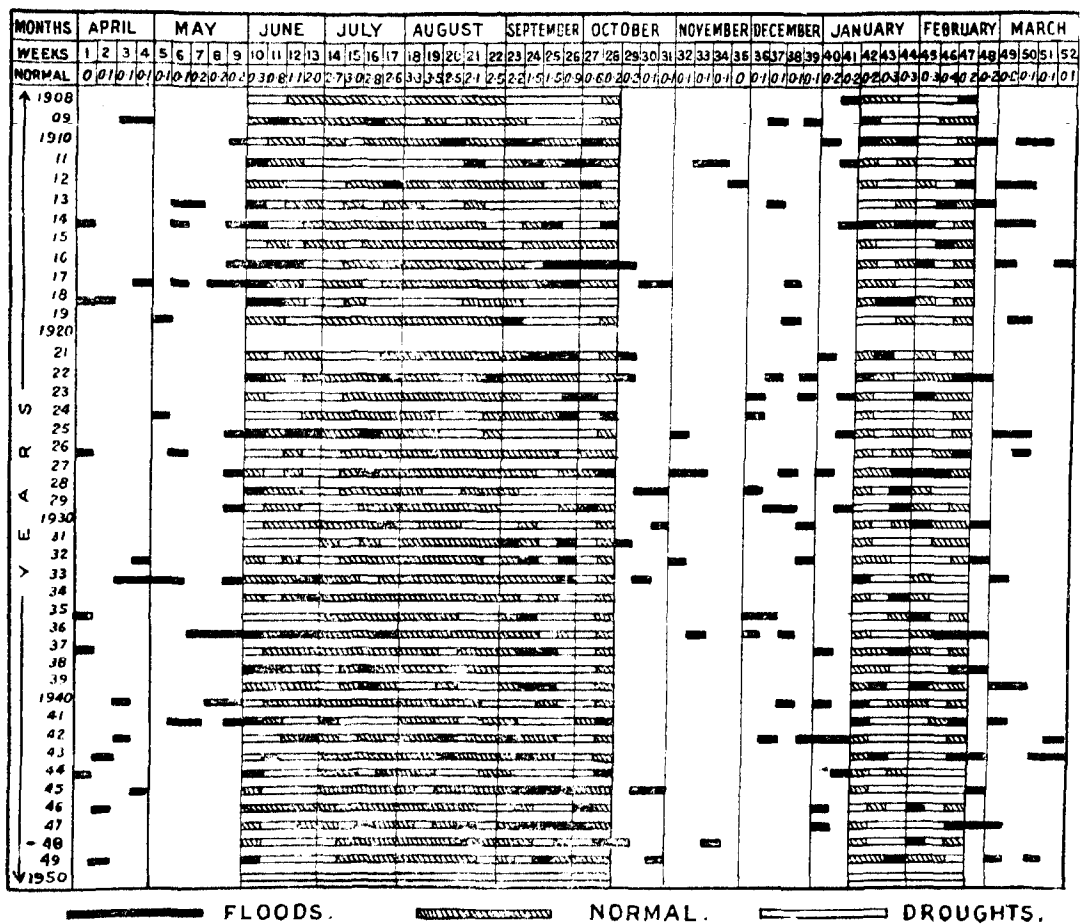


FIG. 13. Rainfall of Uttar Pradesh (West) week by week

part of the north-east monsoon. The wet season so defined consists of 39 weeks as compared to 17 in the case of Gujarat. We may, therefore, be led to expect a larger proportion of abnormal spells. This, however, is far from being the case. The occurrence of a large number of normal weather spells is even more pronounced than in the Madhya Pradesh. Flood spells lasting 4 weeks continuously occurred in 1911, 1919 and 1931; 1944 alone had a spell of 5 weeks.

Similarly, droughts of 5 weeks' duration occurred in 1908, 1918, 1921, 1926, 1939 and 1945 (6 times), of 6 weeks' duration only twice in 1917 and 1923 and of 7 weeks' duration only once in 1947. Most of these prolonged droughts, except for that in 1918, occurred during the north-east monsoon. This area is indeed very fortunate in having a dependable rainy season.

The three examples given above are of the monsoon type where the rainy season consists of pre-monsoon—monsoon—post-monsoon periods which over-lap one another into a single wet season. This type prevails in north-east, central and peninsular India.

The next example is that of Uttar Pradesh—West, typical of North-West India—where the monsoon rainfall is followed by a spell of dry weather and the winter rainfall occurs in a second wet season, as it were. Fig. 13 shows the weekly distribution of rainfall during 40 years. During the winter rainy season lasting just 6 weeks (January-February) a drought spell of 5 weeks' duration occurred once in 1945 and of 4 weeks' duration thrice in 40 years, spells of flood have seldom exceeded 2 weeks' duration while normal rain-spells extending up to 2 weeks are quite frequent. During the monsoon season long spells of 'normal' rainfall often occur extending occasionally even up to 3 months. Flood-spells seldom exceed 3 weeks' duration whereas drought spells of 5 weeks or more are not rare.

Diagrams as in Figs. 10 to 13 showing the variability and the dependability of rainfall have been prepared for each of the 30 rainfall sub-divisions of India and the results have been discussed recently by T. S. Govindaswamy (144).

#### SOME SEASONAL FEATURES OF RAINFALL, TEMPERATURE AND HUMIDITY

The method of presentation adopted in Fig. 9 is very convenient for seeing at a glance the major variations of any climatic factor with time of the year as well as with locality. Fig. 14(a) shows the normal weekly rainfall in the 30 sub-divisions of India during the year. Fig. 14(b) and Figs. 15(a) and (b) show in a similar manner the five day normals of maximum temperature, minimum temperature and the 8 A.M. relative humidity respectively. The four charts of Figs. 14 and 15 do give us a general picture of India's climate in a simple but effective manner.

The main features of Fig. 14(a) have already been described earlier while describing Fig. 9 in Fig. 14(b) the line separating the periods and the areas with maximum temperature above the  $100^{\circ}$  F. limit clearly shows how the summer season matures in the peninsular and central parts of our country in April and May and how, with the onset of the monsoon, the area of high temperatures shifts itself to north-west India in June and July.

Fig. 15(a) shows the seasonal march of the minimum temperature in the different parts of India. The line which marks out the areas on the diagram with the minimum temperatures less than  $50^{\circ}$  F. shows how the cool season or winter sets in and how long it lasts in the different parts of north and central India.

The winter season naturally begins earlier and lasts longer in North India than in the central and southern tracts, the duration as well as the intensity of the cold season decreasing rapidly as one proceeds towards the equatorial region.

In Fig. 15(b) the lines showing the areas on the diagram with humidity greater than 80 per cent. show clearly the long seasons of high humidity in north-east India and the maritime tracts of the Peninsula. During the summer, before the onset of seasonal showers, the relative humidity is lower than 40 per cent. in the interior of the country which is continental (*i.e.*, away from the moderating influence of the seas). These are the tracts where the familiar wet *khas khas* screens can be effective in bringing down the temperature inside dwellings during summer.

Mention may be made here of the statistical investigations of Kalamkar (93, 94) on predicting maximum temperatures, of Satakopan (95), Rao (96) and Rajagopalan (97, 98) on rainfall trends, of Ramdas and Satakopan (99) on secular trends, of Rao and Pimpalwadkar (100) on periodicity and of Ramdas and Rao (101) on the prediction of the date of establishment of the south-west monsoon.

#### WEATHER ABNORMALITIES AND CROPS

The march of the weather factors during a season is never smooth and regular (111), as is the case with their normal values as shown in Figs. 14 and 15. On any day, week, or month in a given year, the actual weather factors deviate at random and in varying degrees from the normal values. Often, fluctuations of weather occur abruptly and with a violence which crops can hardly withstand. The following are the major weather abnormalities and destructive meteorological phenomena, which affect crops adversely in India :

1. Excessive rains (floods)
2. Scanty rains (droughts)
3. Untimely rains
4. Storms, cyclones, depressions
5. Thunder-storms, hail-storms and dust-storms
6. Cold waves accompanied by frost
7. Heat waves
8. Excessive or defective insolation
9. High winds

#### *Floods*

Fig. 16 is a map of India indicating the frequency of heavy falls of 5 inches and above in 24 hours. Fig. 17 indicates the heaviest fall in 24 hours. Both figures are based on data for the period 1891 to 1920 (115). Fig. 17 shows that :

- falls exceeding 5 inches in 24 hours have occurred over the whole of India excluding north-east Baluchistan and parts of the N. W. Frontier;
- falls have not exceeded 10 inches in 24 hours over most of the interior of the Peninsula and of Burma and in a few districts in the central parts of the country ;
- falls of 15 to 20 inches in 24 hours have occurred all along the West Coast including Gujarat and Kathiawar, on the South Coromandel coast, on the North Burma coast, in South Assam, in Bengal and the foot of the Himalayas;
- a few isolated falls of 20 inches and over in 24 hours have occurred in the plains; and the greatest fall of 40 inches in 24 hours has occurred at Cherrapunji in the Khasi Hills.

MONTHS	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR
WEEK ENDING ON	8 3 20 27	4 11 18 25	1 8 15 22 29	5 12 19 26	3 10 17 24 31	7 14 21 28	5 12 19 26	2 9 16 23 30	7 14 21 28	4 11 18 25	1 8 15 22 29	5 12 19 26
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(a)

MONTHS	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	
ASSAM	158 165 169 174 178 182 186 190 194 198 202 206 210 214 218 222 226 230 234 238 242 246 250 254 258 262 266 270 274 278 282 286 290 294 298 302 306 310 314 318 322 326 330 334 338 342 346 350 354 358 362 366 370 374 378 382 386 390 394 398 402 406 410 414 418 422 426 430 434 438 442 446 450 454 458 462 466 470 474 478 482 486 490 494 498 502 506 510 514 518 522 526 530 534 538 542 546 550 554 558 562 566 570 574 578 582 586 590 594 598 602 606 610 614 618 622 626 630 634 638 642 646 650 654 658 662 666 670 674 678 682 686 690 694 698 702 706 710 714 718 722 726 730 734 738 742 746 750 754 758 762 766 770 774 778 782 786 790 794 798 802 806 810 814 818 822 826 830 834 838 842 846 850 854 858 862 866 870 874 878 882 886 890 894 898 902 906 910 914 918 922 926 930 934 938 942 946 950 954 958 962 966 970 974 978 982 986 990 994 998 1000												
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FIG. 15 (a). Normal minimum temperature (F°) at 5-day intervals; (b) Normal relative humidity percentage at 5-day intervals (8 A. M.)

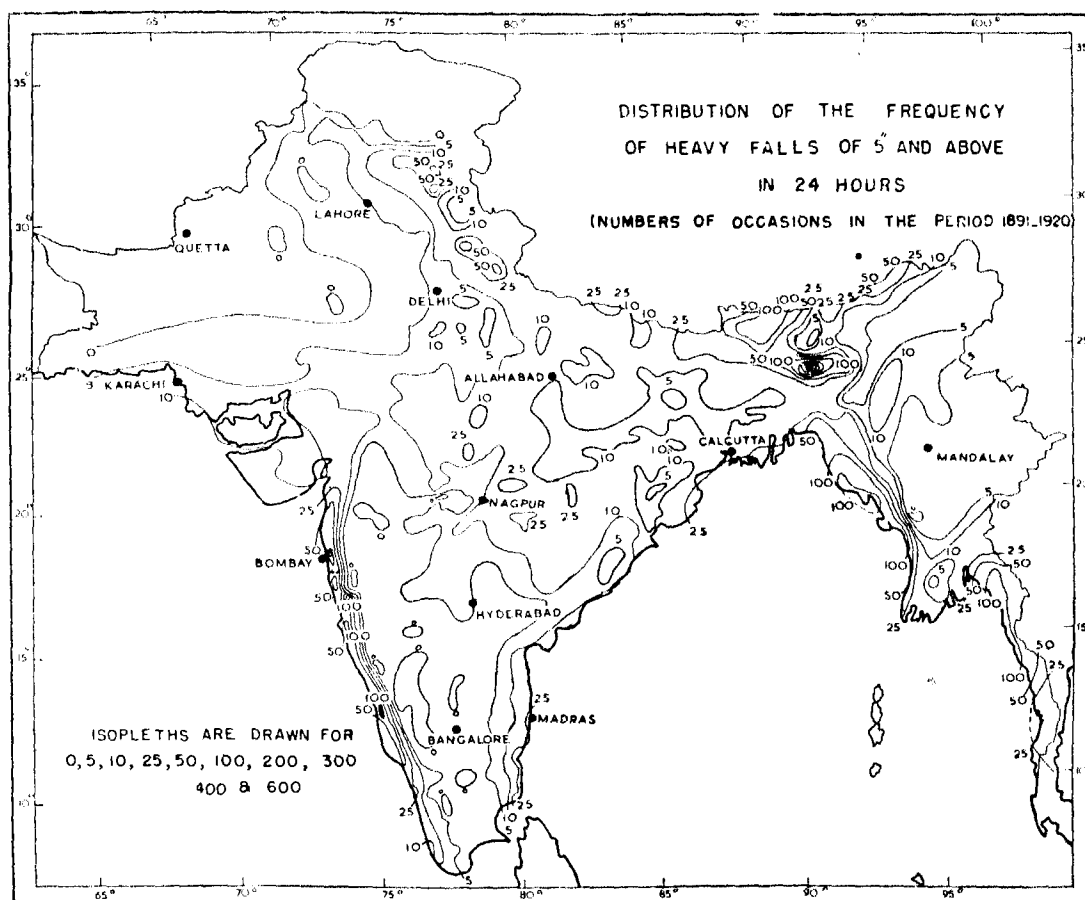


FIG. 12

FIG. 16. Distribution of frequency of rainfall

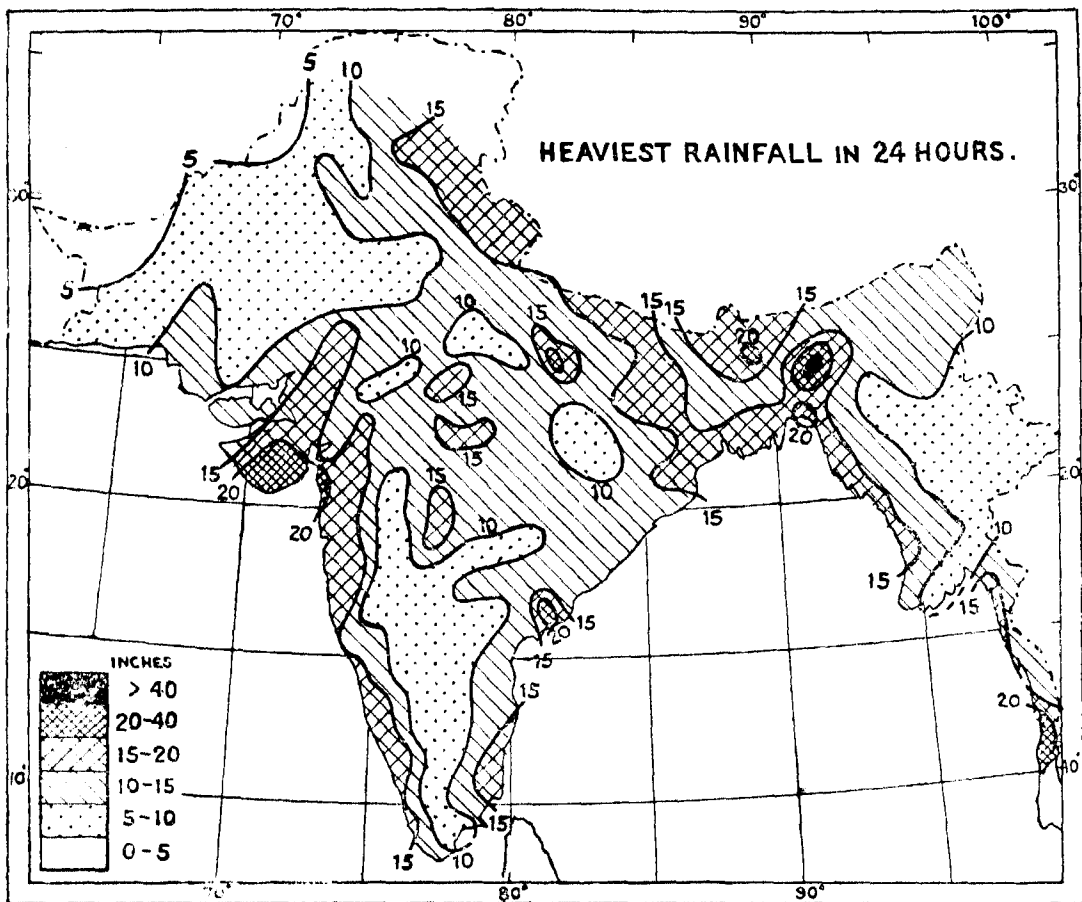


FIG. 17. Heaviest rainfall in 24 hours

When heavy rainfall occurs consecutively on a number of days and particularly over the catchment areas of rivers, the magnitude of the ensuing floods may well be imagined. For such large-scale phenomena the remedies depend on the large-scale planning by the State in connection with the many multi-purpose or hydro-electric schemes. A careful sifting of the facts of forestry in India has revealed that we are paying now for the errors of the past, for the indiscriminate and wholesale destruction of our forests. The forest departments are now appreciating the vital importance of a well-developed forest cover over a catchment area for checking erosion and preventing too rapid a drainage of the flood waters into rivulets which discharge into major rivers and their tributaries. By retarding surface drainage, the down rush of the waters is stemmed and the peak of the flood is delayed and smoothed over. Planned afforestation of the denuded areas is one of the remedies and the activities of the State in this direction and for hydro-electric projects in the different parts of the country should receive every support.

For floods, the individual farmer can only keep the drainage channels of his fields open. The development of flood-resistant varieties of crops is another remedy which is engaging the attention of plant breeders and agricultural workers.

### *Droughts*

The problems raised by droughts or prolonged dry spells relate first of all to the careful collection of rain water in a system of tanks, bunds, lakes, etc., and its distribution by a planned system of irrigation. It must be remembered that rainfall has a high variability with reference to locality, particularly in the areas of scanty rainfall like Rajasthan, Gujarat, etc. In such areas the irrigation engineer will be well advised to construct a number of smaller reservoirs, casting his net wide, as it were, rather than set up one big reservoir.

There are also problems relating to the conservation and most economical use of the available water. Wherever feasible, resort should be had to sub-soil irrigation (47, 63, 64, 65, 66), *i.e.*, delivering water at the root zone of the plants through suitable pipes. In arid parts like Rajasthan such a system, where practicable (*i.e.*, in orchards), will minimise water loss by evaporation which occurs in the case of surface irrigation.

Methods of conserving sub-soil moisture by surface mulching are in use over dry-farming tracts where droughts are the rule; but in such areas the soil has a high water-holding capacity. It is possible also to check air movements near the ground by building up a system of wind-breaks and so keep down the evaporation losses\*. In areas susceptible to droughts, drought-resistant or drought-escaping varieties of crops and plants should be introduced.

### *Cyclonic Storms and Depressions*

One of the features of the colossal meteorological phenomena like cyclonic storms and depressions is that their favourite directions of movement and speeds are generally understood so that the dates of their onset over a region and the associated heavy rains and squally weather can be forecasted. On receipt of the warning, precautionary measures are taken by shipping, aviation, railway engineering, irrigation interests, etc. Agriculturists also take advantage of these warnings by trying to save the growing crops, stored grain, livestock, etc. Warn-

\*'Evaporation Control' by covering the free water surfaces of lakes, tanks and reservoirs with a mono-molecular film of a cetyl alcohol is a very recent development. By using this technique evaporation losses are reduced under laboratory conditions, by about 50 per cent. Preliminary experiments to test this method are being started in India this year (1958) over a few selected reservoirs.

ings of untimely rain and heavy rain, especially during sowing and harvest times will be particularly useful as sowing can be postponed and harvesting hastened, whenever such disturbances are expected. Against the large-scale floods and very severe squalls the cultivator can do little, but if forewarned, valuable lives can be saved. The importance of prompt and efficient reception of weather bulletins and warnings through the All India Radio will be referred to later.

### *Thunder-storms, Hail-storms and Dust-storms*

These are comparatively local in character, although they may also be associated sometimes with depressions, storms, etc. which affect a bigger area. They usually occur before the onset and after the withdrawal of the monsoon. In their mode of occurrence there are points of similarity between thunder-storms, dust-storms and hail-storms. In the absence of sufficient moisture in the atmosphere we can get only a dust-storm. When enough moisture is present a thunder-storm results. A hail-storm is a particularly violent thunder-storm. Though short in duration, the precipitation and associated squalls during thunder- or hail-storms are often very violent. Squalls up to 80 or 100 miles an hour in short spells may sometimes occur. In many parts of India, e.g., in the Deccan, pre- and post-monsoon thunder-showers are the main sources of soil moisture for growing crops.

Hail-storms are, however, very destructive to standing crops and even to livestock and human beings. By examining the daily records of hail for a period of 35 years and of 140 weather reporting stations in India, charts showing the frequency of days with hail-storms (expressed as the number of occasions per 100 years) in different months of the year and in the year as a whole have been prepared [1,106(d)]. These show that the frequency of hail-storm is small in early winter but increases generally as the season advances into summer. Once the monsoon sets in, the phenomenon is practically absent in the whole country. After the withdrawal of the monsoon, hail-storms begin to occur in the north and central parts of India, but, until the winter advances into spring, the increase in frequency is not conspicuous. Fig. 18 shows the annual frequency of hail-storms in 100 years. The frequency of days with hail is about 10 per year over the Himalayas. This decreases rapidly to once in two years over the adjoining plains. Over lower Bengal the hail-storms occur usually once a year. The area consisting of Madhya Pradesh forms another centre of frequency of the order of once a year. The coastal tracts of the Peninsula are regions where hail-storms are comparatively rare. The largest known hail-stones are about 5 inches in diameter weighing about 1½ pounds. The smaller sizes are more frequent. Hail-stones have been reported sometimes to break through ordinary roofs, corrugated iron sheets, etc. Protection against violent hail-storms is, therefore, difficult particularly under rural conditions. But the farmer who is warned before-hand can harvest his crops if they are already ripe. The importance of warning for hail-storms may be realised from the fact that in many years in areas like the Uttar Pradesh, Madhya Pradesh, Madhya Bharat, Punjab and occasionally the Bombay Presidency and Hyderabad, the local governments have to grant large remissions of land tax owing to large-scale destruction of crops by this phenomenon. The possibilities of compensation by suitable 'insurance' are now under active consideration of the authorities concerned.

### *Cold Waves and Frost Hazard in India*

During winter, atmospheric disturbances called western depressions enter India from the west at intervals of about a week and move eastwards through

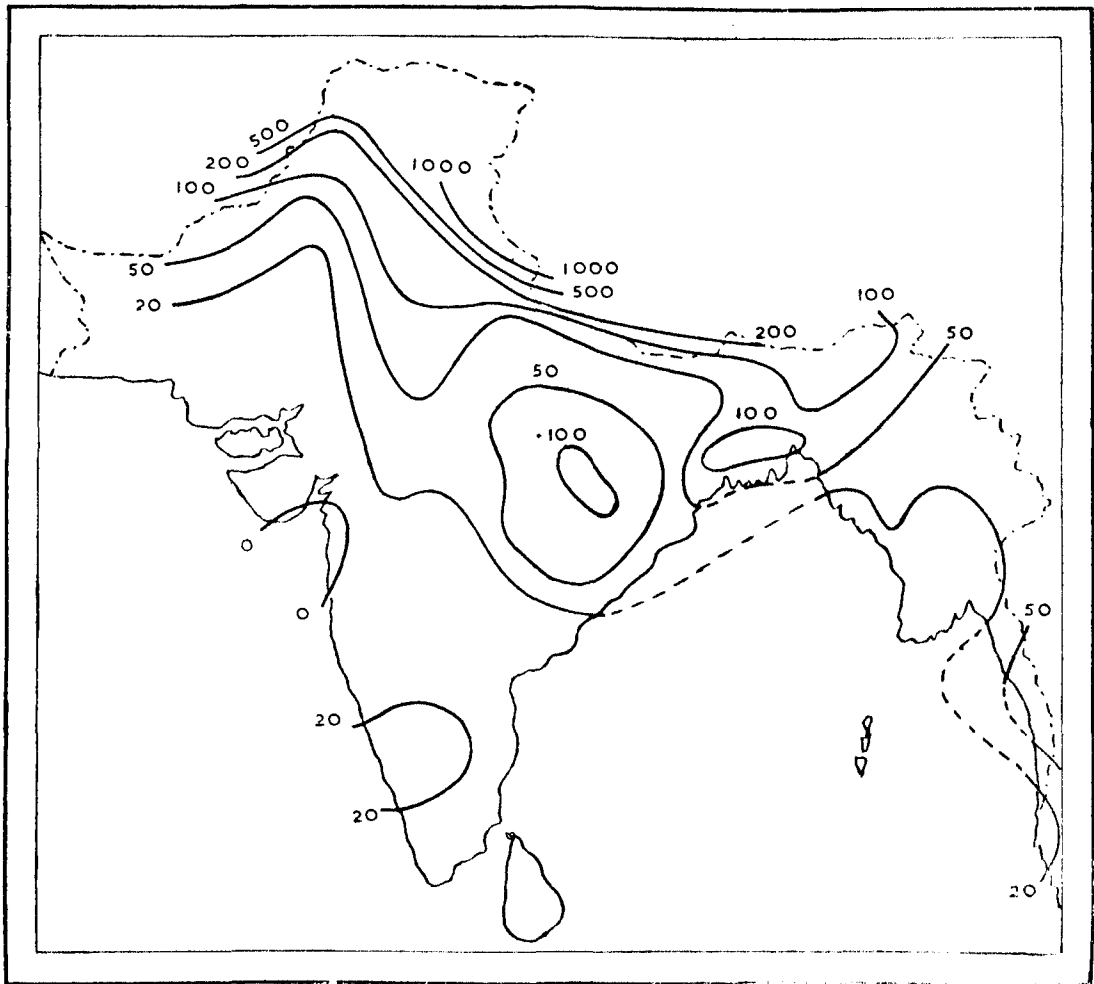


FIG. 18. Frequency of days of hail-storms in 100 years (Annual)

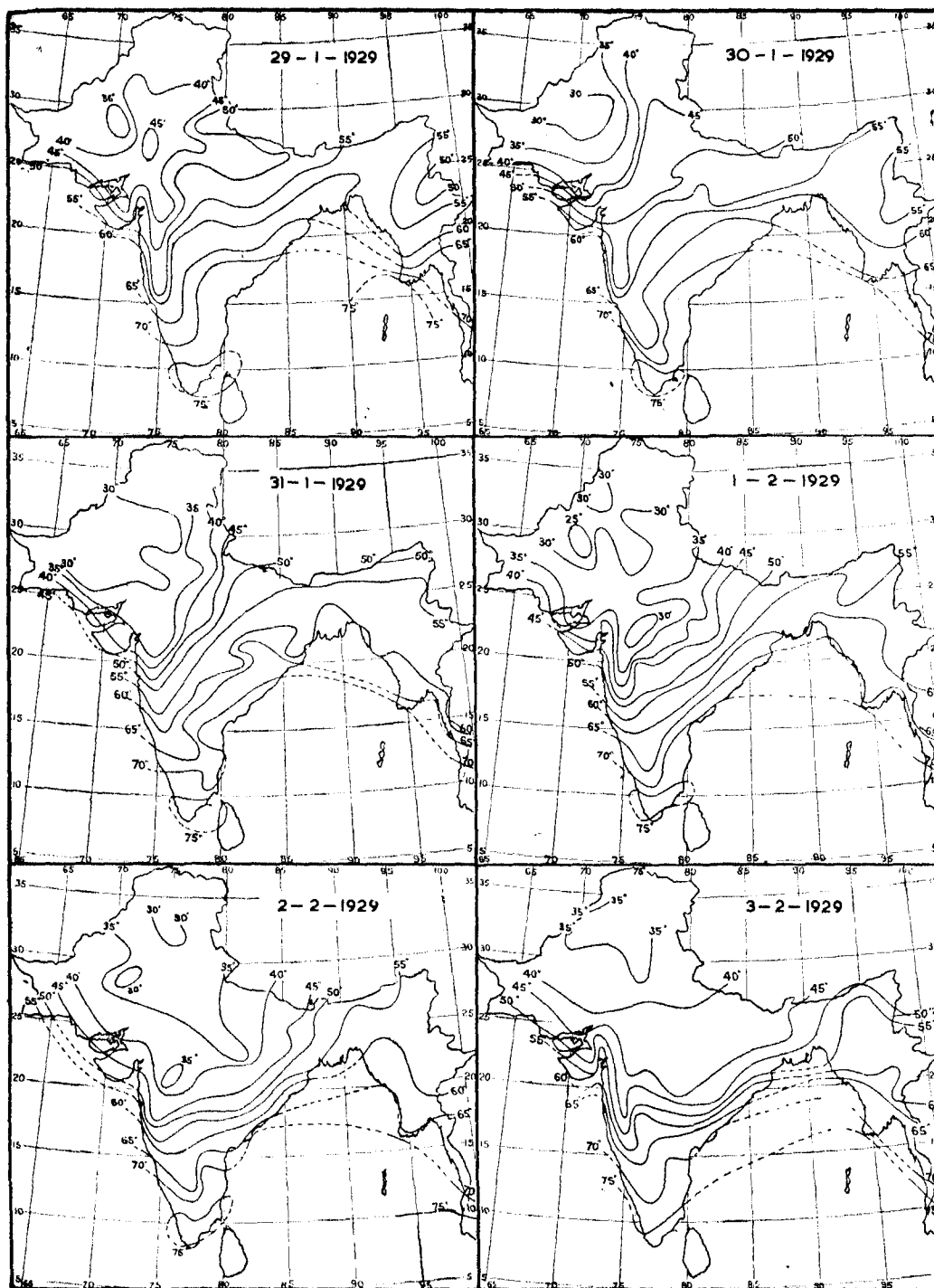


FIG. 19. Minimum temperature (F°) on each day during the period 29th January to 3rd February, 1929

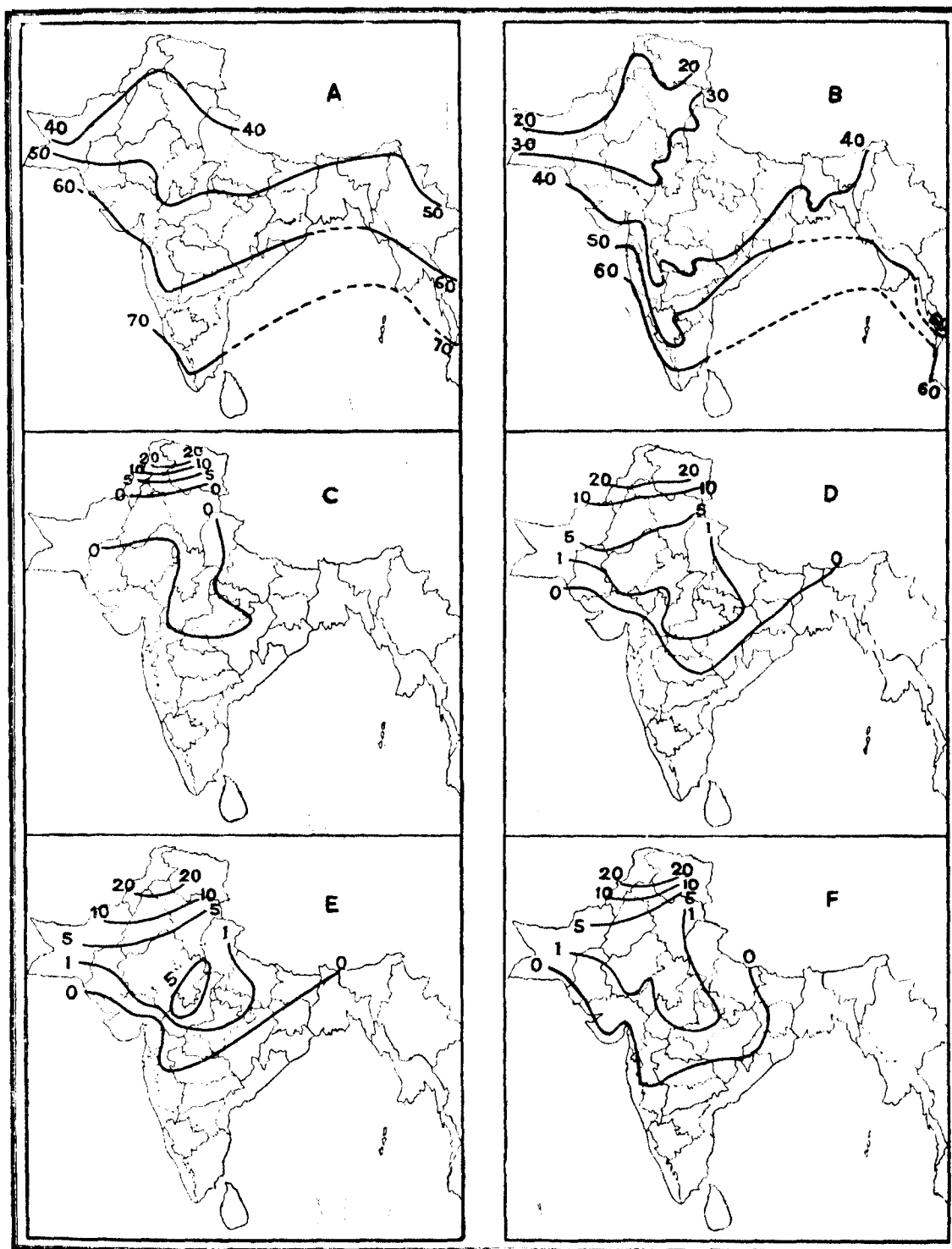


FIG. 20. Frequency of frost in India

(A) Mean daily minimum temperature °F January. (B) Lowest minimum temperature °F (recorded up to 1920). (C) Frequency of days with radiation minimum temperature below 30 °F in November. (D) Frequency of days with radiation minimum temperature below 30 °F in December. (E) Frequency of days with radiation minimum temperature below 30 °F in January. (F) Frequency of days with radiation minimum temperature below 30 °F in February.



FIG. 21. Jowai crop laid low by high winds

the Indo-Gangetic plains and the central parts of the country towards the north-east frontier of India. The approach of a depression is heralded by the appearance of high clouds, movement of air from southerly latitudes and rise of air temperature. Within a day or two, the clouds lower and drizzling weather ensues. So long as the place lies in the warm sector of the depression, there is no danger of low temperatures; but the warm sector moves eastwards and is soon followed by the cold waves, when cold dry winds from the north or northwest, up to about four thousand feet in depth, pour into the region. The cold wave in its turn extends or moves across the country weakening in the meantime. The intensity of a cold wave as well as the extent of the country it affects depend on the intensity and the area of the depression with which it is associated. Sometimes, the anti-cyclone over Tibet and Mongolia which is the main reservoir of cold air for Asia is itself shifted westwards towards Europe and if at the same time a western depression passes through Persia and northwest India, a very severe cold wave sets in behind the depression. The phenomenal cold wave which visited India during the period 29th January to 3rd February 1929, was of this type.

The six charts shown in Fig. 19 indicate the minimum temperatures recorded during the above period. Fig. 20(a) represents the mean daily minimum temperature in January, and (b) the lowest minimum temperature recorded up to 1920. A perusal of these charts indicates that in the regions to the north of latitude 18° north, the minimum temperature may sometimes fall by about 20°F below the normal, whereas to the south of this latitude the corresponding fall will be only of the order of 10° F.

### *Frost Hazard*

The minimum temperature attained by objects near the ground, like crops in a field, which are fully exposed to the sky is lower than the air temperature in the Stevenson Screen. This difference has been estimated with the aid of grass minimum (radiation minimum) temperature records maintained at a number of observatories in India and ranges from 8° to 12° F. Fig. 20(C), (D), (E) and (F) indicate the mean frequency of days with radiation minimum temperature below 30°F in the months of November, December, January and February constituting the cold weather period. From these charts it is clear that the North Punjab is the area most liable to the incidence of frosts. As one moves southwards or eastwards from this tract the liability to frost decreases rapidly. It must be borne in mind, however, that in the Punjab the crops may be expected to be more resistant to cold than those in lower latitudes.

Whenever a cold wave with possibility of frost is expected, warning messages are put out on the radio as well as by telegrams and steps can be taken by the farmer to save his crops. The methods of preventing frost damage have, therefore, to be investigated.

It is known that topography has much to do with the degree of immunity of a locality against killing frost. The bottom of a valley collects all the cold air flowing during the night from the neighbouring slopes. The farmer should try to avoid such localities for crops which are susceptible to cold. Slopes are less liable to frosts as cold air cannot collect on them and are, therefore, to be preferred for locating horticultural gardens.

### *Heaters and Wind Breaks*

During cold waves in India, there is often a flow of cold air over the country. Across avenues the flow of air is checked and the cooling of vegetation on the leeward side of such wind-breaks is found to be less severe than on the windward side. With important money crops like vines and sugarcane, it is possible and often

worthwhile to try heating the orchard by means of artificial heaters, after reducing the air movement by means of wind-breaks. At Nasik, experiments conducted by the Agricultural Meteorological staff showed that by using 400 country fires per acre and with wind-breaks of *jowar* stalks it was possible to warm up the air in the garden by about  $10^{\circ}\text{F}$  which will be sufficient to prevent freezing on a frosty night.

Within short crops like wheat it is more difficult to alter the local climate by artificial heating or smudging. Irrigation as a protective measure may be useful during cold waves of short duration. During protracted spells, however, a considerable amount of solar heat is lost by evaporation from the wet soil, and the protection afforded by irrigation tends to be counteracted. The subject of frost protection in India deserves further study. The damage due to frost is very large in some years as is borne out by the large revenue remissions granted by the States of North and Central India. The feasibility of covering frost risks by crop insurance is now engaging the attention of government.

### *Heat Waves*

Just as cold waves are injurious to crops in winter, heat waves in summer are also prejudicial to their well being. The frequencies of days with maximum temperature exceeding  $100^{\circ}\text{F}$ ,  $105^{\circ}\text{F}$ ,  $110^{\circ}\text{F}$ ,  $115^{\circ}\text{F}$ , etc., have been computed for a network of stations in India (14). From charts showing these frequencies it is observed that the centre of high frequency of maximum temperatures of  $100^{\circ}\text{F}$  and over lies over the Deccan and the Central parts of the country during March, April and May. The frequency increases from 20 days in March to 30 days in May over the Deccan, but once the monsoon sets in, the centre of high temperatures shifts rapidly towards North-west India. In July and August, south-east Madras is another area of high temperatures. The frequencies of days with temperatures of  $105^{\circ}\text{F}$ ,  $110^{\circ}\text{F}$  and over, show similar tendencies.

### *Excessive or Defective Insolation High or Low Soil Temperatures*

Insolation is a function of the inclination of the solar rays, length of the day and transparency of the atmosphere. During clear days in summer, the temperature of the ground surface in India reaches very high values (60), particularly on days when air movement is weak. Values of the order of  $167^{\circ}\text{F}$  ( $75^{\circ}\text{C}$ ) are often recorded over black soils. Experiments made at Poona show that on such days a thin cover of white substance like chalk can depress soil temperature at noon by as much as  $36^{\circ}\text{F}$  ( $20^{\circ}\text{C}$ ). A black cover (e.g. charcoal powder) is useful for absorbing the insolation fully and heating up the soils as much as possible in days or seasons with weak insolation. The effect of wetting the surface is to depress soil surface temperatures by about  $20^{\circ}\text{F}$  ( $15^{\circ}\text{C}$ ). But the cooling effect is due to heat loss by evaporation and lasts only as long as there is enough moisture in the surface layers of the soil. Experiments at Poona show that a thin layer of chalk or a surface mulch of "bagasse" helps not only to keep the soil layers cool but also to conserve soil moisture. The fundamental importance of clear sunshine to photosynthesis in plants is well-known. During cloudy weather this activity is decreased, thus retarding growth. Also, conditions become favourable for the incidence of certain pests and diseases if such weather is unseasonal. Cloudiness is also injurious to crops during a critical epoch like flowering when seed setting is affected.

### *High Winds.*

The effects of high winds are many. The mechanical effect and possible damage to standing crops are obvious. Fig. 21 shows a crop of *jowar* laid low by high winds during a depression in October 1938.

If the air is cold, the effect of the high winds is to cool exposed objects very rapidly and the result of such cooling is disastrous if frost also sets in. On the other hand, if the air is hot, the saturation deficit will be high and the rate of evaporation from water reservoirs (2) and transpiration from plants and trees will increase enormously. On such occasions plants are known to wilt and die owing to the rapid desiccation. The shrivelling effect of hot winds on grains at the milk stage is well-known.

It is also obvious that the clear sweep of the winds over crop fields should be checked and wind-breaks are the only remedy. Wind-breaks should consist of a line of trees planted at right angles to the prevailing wind direction. When the trees grow up, the gaps between them must be blocked by growing another line of younger trees or shrubs. The United States of America has considerable experience on this subject. "An ideal wind-break for checking wind currents would have the contour of an earth-dam. In the Central rows would be planted the tallest trees such as cotton-wood; on either side, rows of shorter trees such as ash and locust, and outside of these, low bushes or cedars. Such a wind break would not be easily penetrated and its inclined surface would direct the air currents upwards and relieve the wind pressure". [*Farmers' Bulletin* No. 1405.]

In India, we may lay down similar specifications for an ideal wind-break of trees and shrubs which grow well in our climate. The numerous effects of a wind-break are as follows:

1. Checking air movement and thus affording protection fields and orchards.
2. Checking the movements of the top-soil [wind erosion] and consequent prevention of dust-storms in areas where the soil is sandy or very fine [preventing extension of arid or semi-arid zones characteristic of desert conditions].
3. Reducing evaporation; this happens in two ways, *viz.*, by reducing wind velocity and by decreasing saturation deficiency [as trees etc., transpire moisture into the air].
4. Giving shade to the farm-stead.
5. Providing much needed fuel and timber and preventing valuable cow dung being wasted as fuel.

It is found that the loss due to space taken up by wind-breaks and due to water removed from the fields by the root systems of the trees and shrubs is more than compensated by the increased yields in the protected area and by the value of the fuel and timber.

During severe atmospheric disturbances like cyclonic storms, depressions, thunderstorms, etc., squalls or very high winds are experienced. Fig. 22 shows the maximum wind pressures likely to be attained in different parts of the country(116). It may be noted that exceptionally high wind pressures are experienced mainly in the coastal tracts of the country.

Before concluding this topic, it may once again be stressed that a nation-wide awakening and sustained effort in regard to the planting of trees according to a well considered and well organised plan is required not only to afforest our denuded forests but also to provide a proper vegetative cover to the rural parts of our country.

*Daily Weather Service for Agriculturists*

The success of Indian Agriculture mainly depends on favourable weather conditions (111). It is essential, therefore, for the farmer to have a knowledge of the anticipated weather as far ahead as the meteorologist can attempt to forecast it in the present state of the science of weather prediction. The farmer has not only to Grow More Food by adjusting his agricultural operations in tune with the weather sequence day by day during the growing season; he has also to Save More Crops from damage by the adverse weather phenomena which have been discussed in the previous section.

The India Meteorological Department inaugurated the WEATHER SERVICE FOR THE FARMER IN JULY 1945. A brief account of this activity is given in the following paragraphs:

*Weather and the Growing Crop*

The healthy growth and yield of crops depend upon certain optimum conditions of rainfall, temperature, humidity, wind, cloudiness, etc., in the air and soil layers with which the plant world is concerned.

There can be little doubt that the farmer stands to benefit by warnings for adverse weather when these are received by him expeditiously. For example, if the farmer knows when the monsoon rains are likely to begin and later how the rainfall would vary during the season, when breaks are expected and when there will be resumption of wet weather, he will be able to time the various important cultural operations, like preparation of seed bed, manuring, sowing, interculture, weeding, transplanting, harvesting, threshing, drying, etc., with the minimum risk to the crop and utilise his limited resources as regards labour, manures, etc. to maximum advantage. There are *critical periods* in the life history of a crop from the date of sowing to the date of harvesting. Sowing time is one of no small anxiety to the farmer. He knows that a heavy shower just after sowing will wash away the seeds and seedlings and depress considerably the germination percentage. Again, if, after sowing is completed, a prolonged drought ensues, the tender seedlings would wither away and the entire crop may need re-sowing. If conditions are favourable during the first phase (germination and early vegetative growth) the crop gets a good start in its career. Thereafter, intervals of clear weather are required for interculture and weeding. During the second phase, *i.e.*, the period of rapid vegetative growth or the 'grand period', as it is called, the water requirement and need for sunshine for photosynthesis are maximum. Then follows the third period, *i.e.*, the period of flowering and reproduction, when vegetative growth ceases. This period of flowering, fertilising and grain formation needs clear weather and minimum cloudiness. Cloudy wet weather during this period can ruin a very promising crop. When the ear-heads are forming and the grains are in the milk stage, one day's hot winds can shrivel up the grains. Even after the entire season has been passed safely, the crop is not free from the danger of adverse or unexpected weather. A heavy shower of rain or hail can do incalculable damage. If warned in time the farmer would hurry up his harvesting operations. Later, when the harvested crop is lying on the threshing floor, it is again at the mercy of any sudden showers.

The weather has also another indirect control. Crops are liable to attacks of various diseases and insect pests during the season. The intensity of their incidence is dependent upon certain favourable weather conditions. One need be reminded only of the cereal rusts and the locust invasions to realise how many major enemies the cultivator has to face.

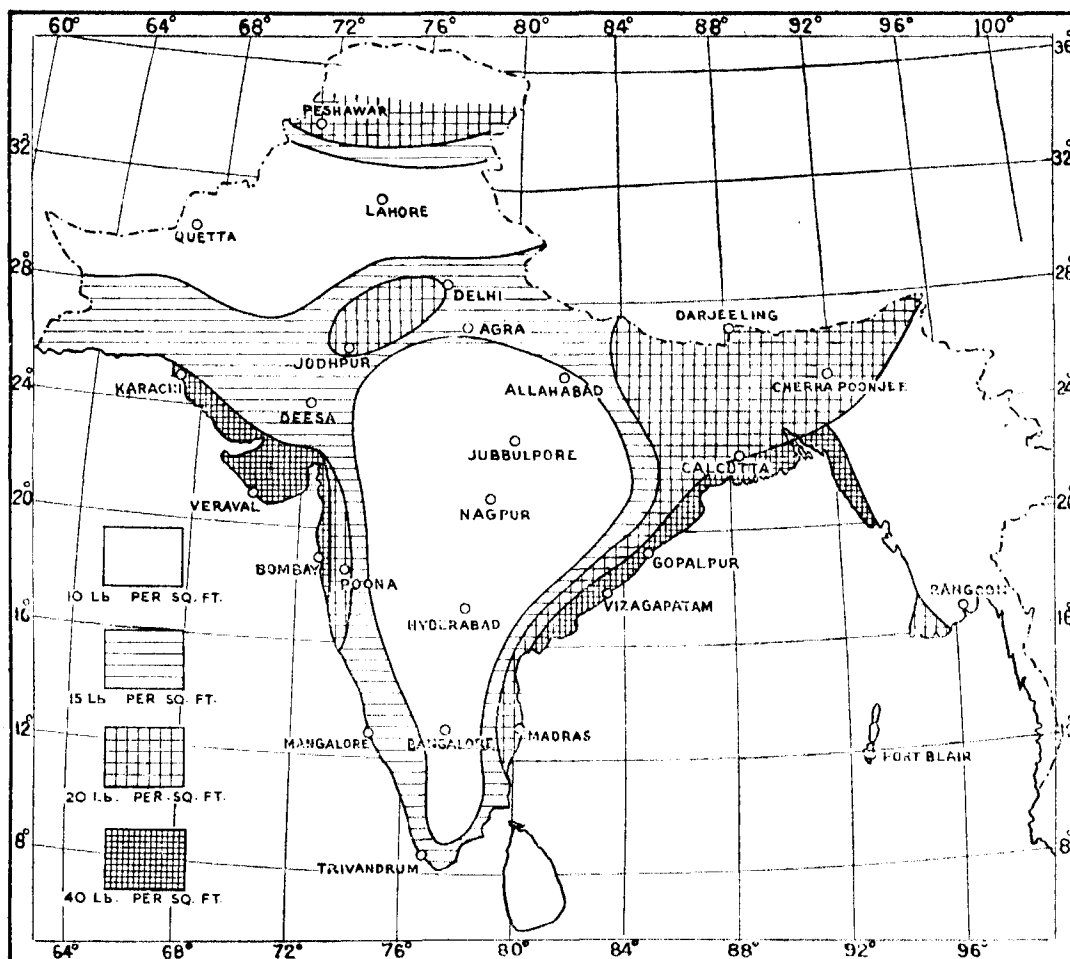
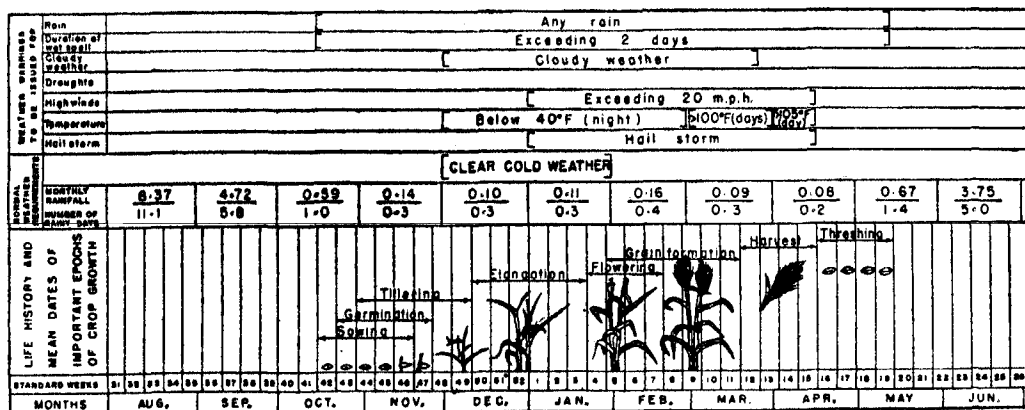
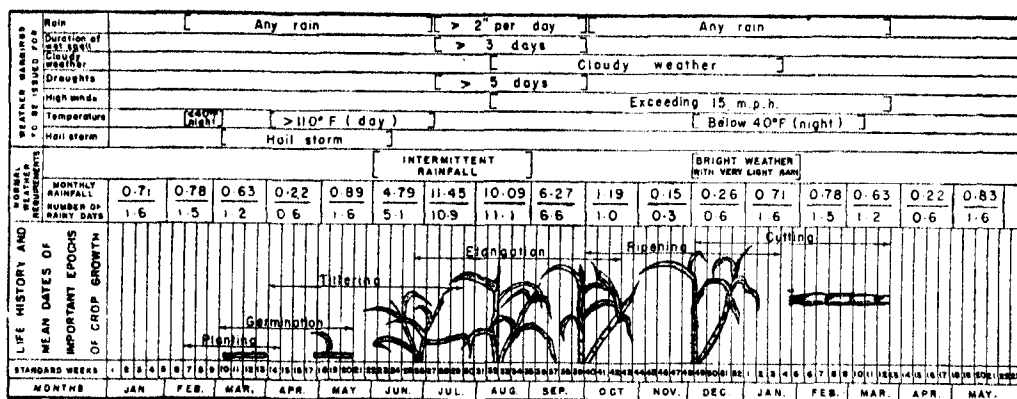


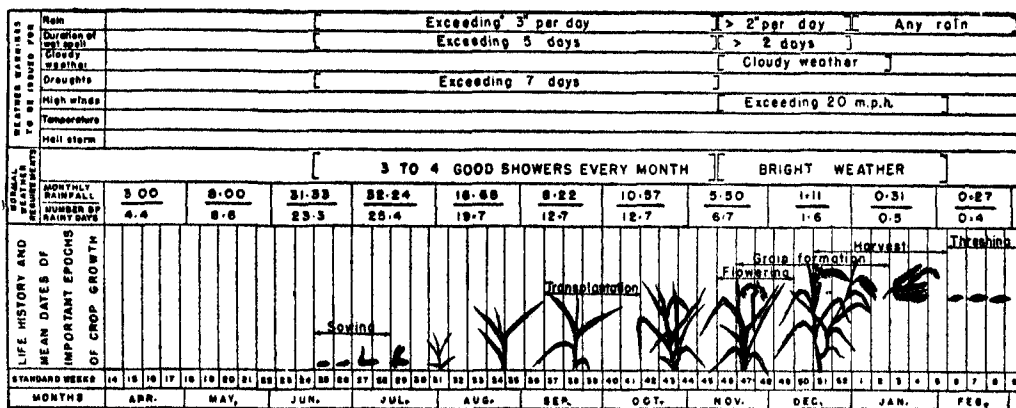
FIG. 22. Indian daily weather report



(a)



(b)



(c)

FIG. 23. Sample Crop Weather Calendars (a) Wheat (b) Sugarcane (c) Rice

### *The Liaison between Meteorology and Agriculture*

The role of Agricultural Meteorology in connection with the 'Weather Service for Agriculture' is a liaison one *i.e.*, to tell the agriculturists what the service means for agriculture; also to tell the weather forecaster what help the farmer and his crops actually need in the shape of weather reports and warnings against adverse weather phenomena. For dealing with these liaison activities a new branch called 'Weather Service for the Farmer (LIAISON) Branch' was added to the Agricultural Meteorology Division at Poona early in 1945.

### *The Questionnaire regarding the Normal Weather and Warning Requirements of Crops in India*

To tell the 'weather expert' what the exact weather and warning requirements of crops are, a detailed questionnaire was circulated to and replies obtained from the agricultural departments in the various Indian States. The replies to the questionnaire were in respect of each of the important crops in each of the 300 districts in India. They contain very valuable information regarding the major crops in the different districts of the country, their dates of sowing, the dates of commencement and duration of the important cultural operations and the important epochs in the life history of the crops during each season and their probable weather requirements. The replies represent what the agricultural departments are able to say in the present state of knowledge.

### *Crop-weather Calendars*

The weather requirements, critical phases, etc., vary from crop to crop and with locality. The wealth of detailed information received from the agricultural departments has been condensed and presented in a pictorial form in what has been called the 'Crop Weather Calendars' (84, 111). The aim has been to prepare one Calendar per district and per crop.

The crop weather calendars have already been prepared for the following crops :

Vol. I— <i>Kharif</i> or monsoon crops	Vol. II— <i>Rabi</i> or winter crops	Vol. III—The sugarcane crop
Rice Cotton <i>Jowar</i> (Sorghum) Jute	Rice Wheat Cotton <i>Jowar</i> (Sorghum) Pulses Tobacco Potato	The sugarcane crop which is sown in India in February- March and harvested after 12-14 months.

Volumes I, II and III of the 'Crop Weather Calendar' album contain about 500 separate Calendars. The Calendars of Vol. I, II and III relating to the districts and crops of their areas have been distributed to the Forecasting Centres at Bombay, Calcutta, Delhi, Madras and Nagpur for their guidance in issuing the daily Farmers' Weather Bulletins, through the local All India Radio stations and newspapers.

Fig. 23 gives three typical or 'sample' Crop Weather Calendars, illustrating the details in respect of (c) Rice, (a) Wheat and (b) Sugarcane.

It will be noted that the Crop Weather Calendar consists of three parts. At the bottom is shown diagrammatically the life history of the crop from the date of sowing

to the date of harvesting, threshing, etc. The important phases like sowing, germination, transplantation, tillering, elongation, flowering, grain formation and harvest are also indicated. These 'phases' cover certain time intervals depending upon variation (a) in crop variety, (b) in sowing date from district to district as well as from year to year and (c) the nature of the crop itself. For ready reference the months and standard weeks are marked at the bottom of the diagram.

The middle of the calendar shows the normal weather requirements as far as the agriculturists have been able to state in their replies to the questionnaire. The normal 'monthly rainfall' as well as the 'number of rainy days' are also indicated here.

The uppermost portion of the calendar indicates the nature of the warnings and the periods during which they are to be issued by the Forecasting Centre concerned.

Diagrams such as these help the weather forecaster to see at a glance what warnings are to be issued to a particular district, during a given weather situation and during a particular phase of the crop. The Meteorologist will thus be in a position to issue his weather bulletins and warnings, keeping in mind the actual needs of the farmer and his crops.

#### *Periodical Revision and Improvement of the Crop Weather Calendars*

The preparation of crop weather calendars is the first attempt of its kind. Naturally, they are 'provisional', pending revision. Criticisms, suggestions and additional information are being received from the agricultural departments from time to time. To reach the target of 'one calendar per district, per crop' the Agricultural Meteorology Section has been in continuous correspondence with the Agricultural Departments in order to obtain full details for some missing districts. These are being received from time to time and fresh Crop Weather Calendars are being added to the albums periodically.

Again, at the end of each of the crop seasons, viz., the 'kharif' and the 'rabi' seasons, the Forecasting Centres are requested to return the crop weather calendars for the past season together with their remarks and suggestions for improvement of each of the Calendars concerned. The remarks and suggestions offered by the Forecasting Centres as well as the Agricultural Departments are carefully studied and the necessary changes incorporated and additional Calendars, if any, added to the albums before they are returned to the Forecasting Centres for further use.

Every effort has been made to improve and revise the calendars periodically during the last few years. After a few more seasons it will be time to consider the question of printing a large number of copies of the albums and make them available for the use of the agriculturists and the general public.

The tehsil-wise replies to the questionnaire now being collected are also being used for revising and checking the existing district-wise calendars.

#### *Regional Meteorological Centres of the India Meteorological Department*

As already pointed out, the actual forecasting of the daily weather and issue of warnings to the public (including the agricultural public) is the responsibility of the five Regional

Centres of the Meteorological Department. These Regions and their headquarters are as shown below:

**CALCUTTA**—(Head Quarters of Region)

*Area of responsibility—*

Bay Islands, Assam, West Bengal, Orissa, Bihar (South) and Bihar (North).

**DELHI**—(Head Quarters of Region)

*Area of responsibility—*

Uttar Pradesh (East), Uttar Pradesh (West), Punjab (I) (including PEPSU and Delhi), Jammu and Kashmir, Rajasthan (West) and Rajasthan (East).

**NAGPUR**—(Head Quarters of Region)

*Area of responsibility—*

Madhya Bharat (including Bhopal), Vindhya Pradesh, Madhya Pradesh (East) and Madhya Pradesh (West)

**BOMBAY**—(Head Quarters of Region)

*Area of responsibility—*

Gujarat, Saurashtra and Cutch, Konkan, Deccan (Desh), Hyderabad (North) and Hyderabad (South)

**MADRAS**—(Head Quarters of Region)

*Area of responsibility—*

Coastal Andhradesa, Rayalseema, Tamilnad, Malabar and South Kanara, Mysore and Travancore-Cochin.

#### *Preparation and Dissemination of Farmers' Weather Bulletin*

The Farmers' Weather Bulletins are prepared by the Forecasting Officers of the Regional Forecasting Centres keeping in view the weather and the warning requirements of the major crops in their areas, as given in the Crop weather calendars.

The Farmers' Weather Bulletins are issued daily by the Regional Forecasting Centres and broadcast by the All India Radio stations in their evening rural programmes. The number of A.I.R. stations broadcasting the weather bulletins has been rapidly increasing and the broadcasts are in the local Indian languages. There is no doubt that the broadcasting of these daily bulletins by A.I.R. will soon attain maximum efficiency and that they will be put on the air in a form that would appeal readily to the farmer.

#### *Rural Receiving Sets*

Coming to the reception side, the utility of the weather broadcasts through the A.I.R. to the public will be in proportion to the number of radio receiving sets actually operating in the countryside or rural areas. Information obtained from the publicity departments in the Provinces and Indian States indicates that, in view of their cultural and propaganda value, the authorities concerned are fully alive to the importance of improving the rural W/T reception facilities.

There is much headway to be made in regard to reception facilities in the countryside. It must be emphasised that the prompt dissemination of the daily Farmers' Weather Bulletin will attain its maximum efficiency only when every village in India has its own wireless receiving set.

### *Other Channels for Disseminating Farmers' Weather Bulletins*

Until W/T facilities fully mature, it is of course imperative to utilise every channel of dissemination in times of importance to the farmer and of urgency or of grave danger to life and crops from cyclones or other destructive weather phenomena. The telegraph system in the country, the wireless network of the police departments, the railway departments, etc., may be pressed into service, wherever and whenever feasible during such grave emergencies. Dissemination of these bulletins by the Community Project Centres, at least to villagers in their immediate neighbourhood is also under trial.

Newspapers too have been playing their part in the dissemination of daily weather bulletins, but this method of propagating the weather news has its own limitations.

### PUBLICITY FOR THE WEATHER SERVICE

#### *The Hand-book 'Weather and the Indian Farmer'*

In order to give wide publicity to the 'Weather Service for Agriculture to explain to the agriculturist the various ways in which the weather forecaster can come to his aid and to acquaint the weather forecaster with the needs of the farmer, an illustrated hand-book entitled 'Weather and the Indian Farmer' has been published and distributed to government departments and to agricultural, revenue and other officials intimately connected with the rural public. The question of issuing a revised edition of the hand-book and its translation into various Indian languages is under consideration.

#### *Addressing Agricultural Conferences*

Whenever conferences are arranged by the Agricultural Departments of the Indian States, one of the officers of the Directorate of Agricultural Meteorology attends by invitation and delivers lectures illustrated by lantern slides, describing the various aspects of the 'weather service for agriculture' or the 'Farmers Weather Bulletins'. The discussions at these conferences are of mutual benefit to the Agricultural as well as the Meteorological Departments and the States are arranging to give increasing opportunity for such valuable contacts.

#### *The Limitations of the Network of Weather Stations*

The need for improving the network of observatories in India was realised at the very commencement of the 'Weather service for Agriculture'. The accuracy of detailed forecasts depends to a considerable extent on this network. The problem of increasing the number of observatories has been engaging the attention of the Meteorological Department since 1945 and new stations are being opened every year. It is hoped that this gap in the organisation will be filled in course of time.

The following quotation from page 12 of the 'Weather and the Indian Farmer' is relevant:

"The network of daily weather reporting stations (observatories) is rather open in some parts of India, there being often only one reporting station representing a group of districts. It will, therefore, be necessary in such cases to deal with blocks of districts instead of the individual districts.

There is a considerable variation as regards the climatic homogeneity of different parts of the country. Rainfall during any particular spell of wet weather will be much more variable both with respect to time as well as locality in some parts of the country than in others. In districts of Rajputana, for example, the rainfall at neighbouring stations on a particular day may be more sporadic and variable than in an area like Malabar, Konkan or Bengal.

Weather phenomena in a tropical country like India have a tendency to occur distributed not always continuously but discontinuously like bubbles in a pan of boiling water. When the temperature of water is increasing and approaching  $100^{\circ}\text{C}$  one can say generally that the water is going to boil, but whether at a particular point there is going to be a rising bubble or not, it is impossible to say.

The present position of the science of weather prediction from the daily weather charts (synoptic meteorology) is such that forecasts and warnings can be issued ordinarily 36 to 48 hours ahead, and in the case of major phenomena associated with storms and depressions 48 to 72 hours ahead.

Phenomena like thunder-storms and hail-storms are often very sporadic in their distribution and it may not always be possible to predict them accurately.

When the monsoon conditions have not been established, and the monsoon is late in arriving (or when there is a break in the monsoon), it may be possible to indicate in a general way that the cultivators will get little or no rain for a few days. But this forecasting for a few days under all conditions comes under the category of "Medium Range Forecasting" which yet requires much study. For agricultural purposes, the medium range forecasting is of very great importance. This is one of the important subjects which are receiving the attention of the India Meteorological Department."

#### *Objective Assessment of the All India Crop Outlook*

In view of the highest priority which the food problem demands, the importance of making periodic reliable estimates of the over-all crop outlook over the country as a whole during the growing season can hardly be over-emphasised.

The problem of improving the quality of weekly crop reports from the States and obtaining them according to a standard plan and in sufficient detail was discussed early in 1948 with the Economic and Statistical Adviser to the Government of India in the Ministry of Agriculture. The necessary instructions were issued to the States, soon afterwards, by the Ministry of Agriculture, with the request that a copy of the weekly crop outlook telegram issued by them to the Government of India may also be sent to the Director of Agricultural Meteorology. These improved telegraphic reports are being received regularly, but the fact remains that they are essentially subjective, based as they are on the mental impressions of the district officials concerned.

Besides aiding Agriculture by issuing farmers' weather bulletins and thereby helping the *Grow More Food* and *Save More Food* campaigns, can Meteorology also help by providing a basis for a comparatively more objective bird's eye view of the crop outlook of India at intervals during the progress of the growing season?

*Weekly Charts of Rainfall, Temperature, Humidity and Crop Growth*

We have recently been engaged in developing methods of tackling this problem with the aid of a set of charts, showing at a glance, for the 30 sub-divisions of India, the week by week progress of the following :

1. the rainfall incidence
2. the maximum and minimum temperatures
3. the relative humidity and
4. the crop development (based on the weekly telegrams already referred to).

Figs. 9, 14 and 15 indicate the method of presentation of the week by week progress of (1), (2) and (3) above, with suitable limits of weather abnormality. The crop chart is also a pictorial one indicating by suitable symbols the progress of cultural operations, crop development and effects of abnormal weather phenomena. These details are all described fully in a recent paper by the present writer and A. K. Mallik in 'Agricultural Situation in India', Vol. III, No. 6, September 1948. (88).

During a current year or season, these charts show at a glance how weather and crops have behaved up to any given date and it is possible to give a reasonably clear picture of the major features of the crop outlook from an inspection of the weather charts alone. Tentative crop outlooks for the 30 sub-divisions of India based on these charts are being sent to the Ministry of Agriculture (Economic and Statistical Adviser), Government of India. These monthly outlooks have been found quite useful for checking the State outlooks by the Ministry of Agriculture who have indicated that the outlooks should be submitted to them regularly, as a permanent measure.

#### CONCLUSION

In the preceding pages we have indicated the various ways in which meteorology is endeavouring to aid Agriculture. The Meteorologist is playing an important role, in this endeavour of making the Farmer wise about the coming weather. The liaison role of Agriculture Meteorology in bringing Meteorology closer in contact with Agriculture in the effort to ensure maximum agricultural production in India has also been referred to.

This contact will no doubt prove increasingly fruitful in the years to come as new methods are developed and new advances are made by research workers.

## THE CLIMATE OF THE AIR LAYERS NEAR THE GROUND

## THE SUN AND ITS RADIATION

All physical, chemical and life processes on the earth are controlled by the sun (5, 31) and its radiation. Our little planet, with its gaseous envelope, revolving round the sun at a

mean distance of 93,000,000 miles intercepts less than  $\frac{1}{2,000,000,000}$  th part of the radiation

emitted by the sun; but the radiation falling on a surface, one square centimetre in area, held normal to the sun's rays, outside the limit of the earth's atmosphere, is about 2 gram calories per minute. When this radiation passes through the atmosphere, it is depleted by the processes of (1) absorption by oxygen and ozone mainly in the ultra-violet region of the spectrum, (2) absorption by water vapour and carbon dioxide in the infra-red region, (3) scattering by the molecules in the atmosphere and (4) scattering by dust and other impurities in the atmosphere.

The cutting off of the extreme ultra-violet (26) by the ozone in the upper atmosphere is of immense significance to life on the surface of the earth; for we can tolerate these radiations only in minute doses, but any excess is injurious. Equally important is the blanketing effect of water vapour and carbon dioxide in the atmosphere which, by absorbing and radiating back to the earth the radiation in those parts of the infra-red region of the spectrum where their characteristic absorption bands exist, prevent the earth from cooling too rapidly by radiation and thus help to keep the earth's surface temperature within safe limits for sustaining life.

The depletion by scattering processes is inversely proportional to some power of the wavelength; i.e.,  $\frac{1}{n}$  'n' has the value of 4 for molecular scattering and smaller values for scattering by dust, fog, etc.

Of all the factors which control the climate of the air and soil-layers near the ground surface, the amount of solar radiation arriving at the earth's surface after passing through the atmosphere is the most important. It is only when we measure experimentally all the factors responsible for the disposal of the energy of solar radiation incident on the ground, that we shall get a real insight into the whole problem of thermal balance at the earth's surface (43).

Records of Kipp and Zonen Solarigraph maintained at the Central Agricultural Meteorological Observatory at Poona show (30, 37) that the total amount of visible radiation from the sun and the sun-lit sky received by 1 sq. cm. of a horizontal surface during a clear day may be as high as 850 gm. cals. During days with overcast skies the value can come down to as low a value as 116 gm. cals. Table 5 gives the mean value of the solar radiation from the sun and sun-lit sky received by 1 sq. cm. of a horizontal surface in gram calories per day as well as the mean duration of bright sunshine at Poona in different months of the year (average for the period 1935-42).

The cloudiness in some parts of the year sets a limit to the amount of solar energy reaching the ground (31). Table 6 gives for 13 stations in India, the average values of the actual number of hours of bright sunshine as recorded by the Cambell-Stokes Sunshine Recorder.

These values are also expressed as percentages of the possible hours of sunshine within brackets. The North-west of India excluding Kashmir ranks highest in regard to the duration of bright sunshine. South-east Madras as well as the Deccan have also a long clear season, but the cloudiness is maximum elsewhere in the Peninsula which is affected by the monsoon, as well as in Kashmir in the extreme north.

It may be pointed out here that clear sunshine plays a vital role in plant growth through photo-synthesis, so that it is essential to have spells of clear sunshine during the season for growing a healthy crop.

TABLE 5. MEAN ENERGY IN GRAM CALORIES RECEIVED FROM THE SUN-LIT SKY PER SQ. CM. OF A HORIZONTAL SURFACE AND THE MEAN DURATION OF BRIGHT SUNSHINE AT POONA

Month	Radiation from the sun and sun-lit sky	Duration of bright sunshine
January . . . . .	482	9.3
February . . . . .	537	10.1
March . . . . .	601	10.1
April . . . . .	623	9.8
May . . . . .	685	10.7
June . . . . .	545	5.9
July . . . . .	399	2.8
August . . . . .	414	4.1
September . . . . .	519	6.2
October . . . . .	537	8.6
November . . . . .	504	9.5
December . . . . .	434	8.7

TABLE 6. ACTUAL VALUES OF ACTUAL NUMBER OF BRIGHT SUNSHINE

Month	Srinagar	Lahore	Quetta	Drigh Road	Agra	Calcutta	Jaipur	Bombay	Poona	Bangalore	Madras	Kodaikanal	Trivandrum
January . . . . .	3.15 (31)	6.93 (67)	7.24 (70)	8.97 (83)	8.68 (82)	8.39 (77)	9.17 (86)	9.58 (86)	9.63 (87)	7.77 (68)	8.28 (72)	6.83 (59)	7.31 (63)
February . . . . .	3.61 (32)	7.14 (65)	8.34 (75)	8.73 (77)	8.88 (79)	7.64 (67)	9.06 (81)	9.96 (86)	10.57 (92)	8.78 (75)	9.97 (85)	8.54 (72)	8.91 (75)
March . . . . .	4.44 (37)	8.39 (70)	8.24 (69)	9.47 (79)	9.53 (79)	8.44 (70)	9.79 (82)	9.76 (81)	10.39 (86)	8.85 (73)	9.59 (80)	8.39 (69)	8.29 (69)
April . . . . .	4.64 (36)	9.11 (70)	8.70 (67)	10.19 (80)	10.08 (79)	8.43 (66)	9.66 (76)	10.48 (83)	10.99 (87)	8.34 (64)	9.70 (78)	7.40 (60)	7.42 (60)
May . . . . .	8.49 (61)	10.10 (73)	10.51 (77)	10.34 (77)	9.77 (73)	8.03 (61)	9.66 (72)	10.08 (77)	10.77 (83)	7.88 (62)	9.69 (76)	7.27 (58)	6.39 (51)
June . . . . .	8.30 (58)	9.32 (66)	11.84 (85)	7.12 (52)	7.76 (55)	4.87 (36)	7.83 (57)	5.39 (40)	6.97 (53)	5.04 (39)	6.68 (52)	4.68 (37)	4.92 (39)
July . . . . .	8.07 (49)	8.30 (59)	11.08 (81)	3.82 (28)	5.98 (44)	3.72 (28)	5.56 (41)	2.27 (17)	2.99 (22)	3.20 (25)	5.23 (41)	3.88 (31)	4.34 (35)

TABLE 6—Contd.

Month	Srinagar	Lahore	Quetta	Drigh Road	Agra	Calcutta	Jaipur	Bombay	Poona	Bangalore	Madras	Kodaik nai	Trivandrum
August . . . . .	5.10 (38)	8.29 (62)	10.60 (81)	4.17 (32)	5.58 (43)	3.94 (31)	4.85 (37)	2.77 (22)	3.81 (30)	4.39 (35)	7.25 (58)	4.65 (37)	5.81 (47)
September . . . . .	6.42 (52)	9.25 (75)	11.46 (93)	7.45 (61)	7.72 (63)	4.82 (39)	7.67 (63)	5.23 (43)	5.26 (43)	5.61 (46)	7.42 (62)	5.40 (44)	7.06 (58)
October . . . . .	7.04 (62)	9.67 (85)	11.16 (97)	9.71 (84)	9.91 (86)	7.00 (61)	10.05 (90)	8.84 (75)	8.25 (70)	5.00 (42)	6.35 (54)	4.44 (38)	5.25 (44)
November . . . . .	5.53 (63)	8.78 (83)	8.93 (84)	9.34 (84)	9.45 (86)	8.73 (79)	9.58 (89)	9.27 (82)	9.18 (82)	6.01 (52)	7.00 (61)	4.60 (39)	6.13 (52)
December . . . . .	4.96 (50)	6.70 (66)	7.51 (72)	8.81 (83)	8.48 (81)	8.55 (80)	8.70 (83)	9.39 (85)	9.37 (85)	7.08 (62)	7.92 (70)	6.28 (51)	7.81 (67)
Year . . . . .	5.81 (47)	8.50 (70)	9.63 (79)	8.18 (67)	8.49 (70)	6.88 (57)	8.47 (71)	7.75 (64)	8.18 (67)	6.50 (53)	7.92 (65)	6.03 (50)	6.7 (55)
Rank*	10	2	1	3	2	6	2	5	3	8	4	9	7

## ROLE OF THE GROUND SURFACE

The surface of the ground is an "active surface" as it plays a very important role in meteorology and is responsible for absorbing solar radiation and thereby warming the air and soil layers near it (16). The darker the colour of the soil the greater is the absorption of solar radiation and the higher temperature attained by the surface. The unabsorbed portion of the incoming radiation is reflected back to space. The percentage of solar radiation absorbed by some typical surfaces is indicated in Table 7.

TABLE 7. PERCENTAGE OF SOLAR RADIATION

Nature of surface	Per centage of solar radiation absorbed
French chalk (white) . . . . .	0 (100 per cent. reflection assumed)
Quartz powder (nearly white) . . . . .	28
Sakrand soil (grey, alluvium) . . . . .	59
Grass covered soil (green) . . . . .	68
Poona black cotton soil (nearly black) . . . . .	84
Charcoal powder (black) . . . . .	96

\*Ranked according to the duration of sunshine during the year, 1 representing the longest duration and 10 the shortest.

The lowering of surface temperatures of Poona black cotton soil by very thin (2 mm.) layers of typical soils of India and chalk powder and by a thin layer of vegetation has been investigated. It is observed that at the maximum temperature epoch the lowering of surface temperatures due to different covers is of the following order of magnitude:

TABLE 8. EFFECT OF LOWERING SURFACE TEMPERATURE

Surface 'cover' used on Poona black cotton soil	Lowering of surface temperature below that of black cotton soil surface at 62°C.
No cover . . . . .	0.0°C
Bangalore soil (red) . . . . .	5.0°C
Alluvial (grey) . . . . .	7.0°C
Chalk powder (white) . . . . .	20.0°C
Vegetation . . . . .	25.5°C

That the surface of the ground is the seat of warming by insolation during day and of cooling by radiation at night and that these heating and cooling tendencies are propagated upwards into the air layers and downwards into the soil layers, can be seen from Fig. 24. In this figure curves are drawn showing the variation of (1) air temperature with height above ground and (2) soil temperature with depth below ground surface at 06.00 hrs. (minimum temperature epoch), 08.00 hrs., 09.00 hrs., 10.00 hrs., 12.00 hrs. and 14.00 hrs. (maximum temperature epoch). The data are typical of the clear season at Poona with little wind. They were recorded above the bare plot of the Central Agricultural Meteorological Observatory (5-1-33).

We note that the diurnal range of temperature is equal to the horizontal distance between corresponding points of the curves OAB and OCD which represent conditions at the epochs of minimum and maximum temperature respectively. The diurnal range is maximum at the ground surface AC, about 37°C. It decreases in the soil very rapidly with depth becoming practically negligible at a depth of 1 foot (40, 43, 46). At O, for example, the thermometer reads 23.3°C. at all hours of the day (while the variation of temperature during a single day is negligible at depths of 1 foot or more, the annual or seasonal variation becomes negligible only at much larger depths).

Coming to the air layers, the diurnal range of temperature falls rapidly in the first few inches above the soil surface, and more and more gradually at higher levels. Thus, even at 35 feet above ground, the diurnal range is of the order of 18°C (about half of that at the surface). In fact, the level in the atmosphere at which the diurnal variation becomes negligible is several miles above the ground, so that a depth of 1 foot in the soil corresponds to a height of several thousands of feet in the atmosphere so far as the decay of the diurnal range of temperature is concerned. We now see why the ground surface is an 'active surface'; it is really the "source" of heating by day and of cooling during the night.

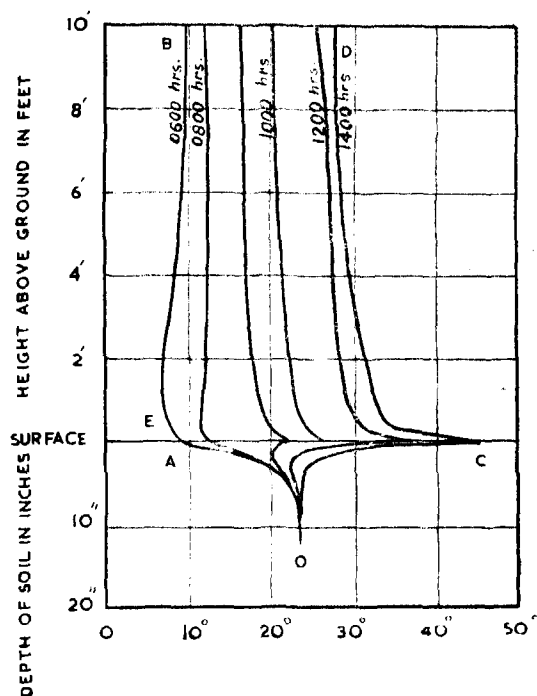


FIG. 24. Diurnal range of temperature in the soil and air layers near the ground surface on 5th January, 1933.

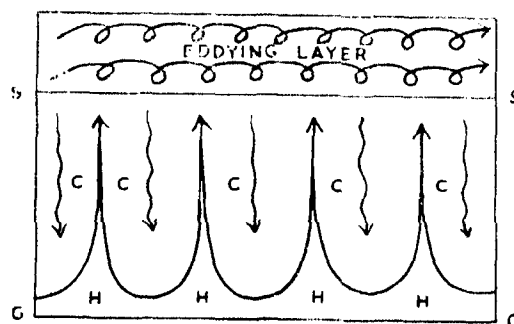


FIG. 25. Shimmering layer with rising hot-currents to H and descending cold currents C.

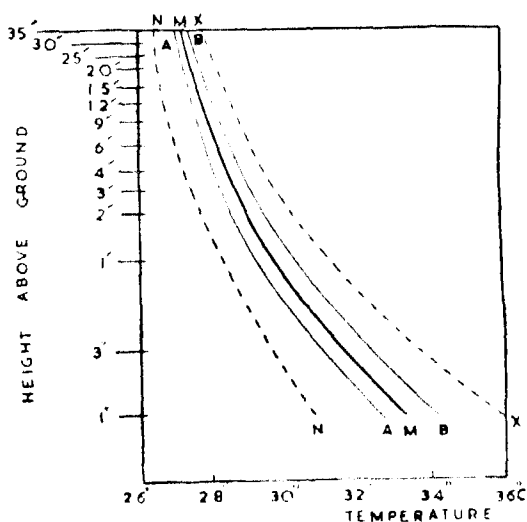


FIG. 26. Fluctuation of air temperature at different levels above ground during the interval 14.30-15.30 hrs. (I.S.T.) on 6th January, 1942.

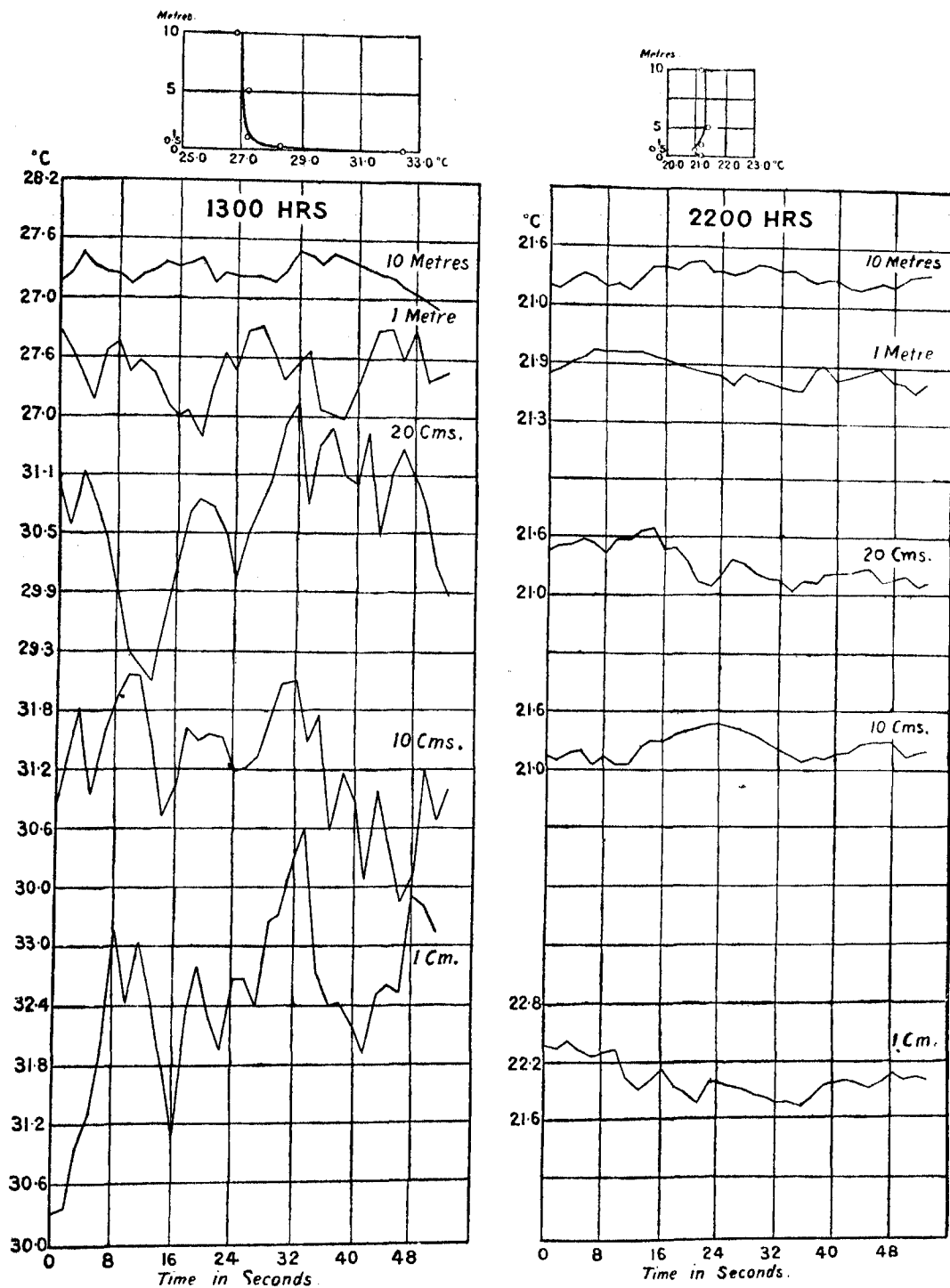


FIG. 27. Short period fluctuation of air temperature at 13.00 hrs. and 22.00 hrs. on 22nd January, 1945.

## AIR TEMPERATURES AT THE MAXIMUM TEMPERATURE EPOCH

On a clear afternoon, the temperature is highest at the soil surface (it can be as high as 75 to 80°C at the surface of the black cotton soil) and decreases very rapidly with height in the first few centimetres and more and more gradually as one moves to higher levels (see curve CD in Fig. 24). The lapse-rate (rate of change of temperature with height or the temperature gradient is extremely high near the ground (5, 112, 113, 114), often exceeding 200,000 times the adiabatic lapse rate (10 °C per Km.) in the first centimetre or two above ground. Like the air temperature, the lapse-rate too decreases rapidly with height. The air in contact with the ground is warmer and, therefore, lighter than the air above. It, therefore, breaks through the colder air in the form of rising columns with compensating downward movements of the air from above. This gives rise to the well known shimmering of distant objects when observed through the air layers, an effect due to the variations of refractive index in what we may call the 'shimmering layer' just above the hot ground. Fig. 25 shows roughly a vertical section of the 'shimmering layer'. GG is the surface of the ground, the columns H, H are the rising currents of hot air, C, C are the descending currents of cold air and SS is the upper boundary of the shimmering layer. Above SS is the free atmosphere with the air layers moving horizontally and full of eddies. The eddying layer is also shown in Fig. 25. The effect of horizontal air motion or wind is to move as well as to incline the shimmer pattern in the direction of the wind, almost like the action of the wind on a tall standing crop. Even strong winds do not wipe out the shimmering layer during the day time when insolation is going on.

The partition SS is well defined at sunrise. Later, under the influence of insolation, the shimmering layer intensifies and thickens, lifting SS rapidly as the day advances. During this process, the partition SS becomes somewhat diffuse. At the maximum temperature epoch, the thickness of the shimmering layer is also maximum. From observations of the decrease of temperature fluctuation with height, it has been estimated that at the maximum temperature epoch the thickness of the shimmering layer is of the order of 200 feet above ground. After the maximum temperature epoch is passed the shimmering layer begins to contract towards the ground, slowly at first and more rapidly towards sunset. At the same time the partition SS lowers rapidly.

## THE MINIMUM TEMPERATURE EPOCH

This epoch represents the conditions after nocturnal cooling has progressed during the night (24, 25, 27, 28, 36). The processes involved in the nocturnal cooling of the ground and the air layers near it have been discussed in a series of papers based on experimental work carried out at Poona, during the past few years. The ground surface emits heat radiation  $\sigma T^4$ . At sunset, insolation is withdrawn and the surface of the ground and the air layers near it begin to cool rapidly as a result of heat by radiative exchange mainly with the water vapour, carbon dioxide, ozone and the dust content in the atmosphere. From observations made with an Angstrom's Pyrgeometer at Poona and elsewhere during clear nights, it has been found that

$$\sigma \frac{S}{T^4} = 0.77 - 0.28 \times 10^{-0.074e}$$

where T is the temperature near the ground, e, the vapour pressure near the ground which is really a function of the total water vapour content W of the atmosphere (According to Hann 'W = 0.21 e approximately'). Thus, when e is zero, S has a minimum value of about half the outgoing blackbody radiation (which cannot be entirely accounted for as

ozone and carbon dioxide radiation to the ground but may probably be attributed partly also to the radiation from the colloidal content of the atmosphere; this aspect requires further investigation). When  $e$  becomes large,  $S$  has a maximum value of about three-fourths of the outgoing blackbody radiation  $\sigma T$ . Thus, nocturnal cooling on clear nights will depend largely on the water content of the atmosphere.

Coming back to the variation of air temperature with height during the minimum temperature epoch, it is found that the temperature decreases with height from the ground level up to 10 or 15 cm. This cold layer phenomenon was discovered by Ramdas and Atmanathan (6) during the winter of 1931-32. It has been verified that the level of the coldest air occurs at the upper boundary of the shimmering layer. This phenomenon is regular in occurrence during the clear winter season all over India and it has recently been observed in U.S.A. (138), and U.K. (139, 140). The origin of the phenomenon as due to radiative cooling of the air layers themselves in addition to the cooling they undergo by conduction from the cooling ground was suggested in a paper by the present writer in collaboration with Ramanathan (25) so long ago as 1935. In Fig. 24, the curve AEB shows the variation of temperature with height during the clear season. The lowest temperature occurs at E as discussed in a number of papers from Poona (5, 6, 7, 8, 9, 10, 25). The layer AE with a lapse rate is the remnant of the previous day's shimmering layer which persists during night whenever the winds are not strong enough to destroy it. Above this thin unstable layer we have the stable or stratified air layers associated with the well known inversion layers EB (Fig. 24) where temperature increases with height. Thus, after nocturnal cooling starts in the evening, we have the contracting shimmering layer supporting the stratifying inversion layer above. The fact that there is a reversal from lapse to inversion at the partition SS (Fig. 25) enables one to locate it as a sharp or well-defined partition at sunset and later during the night and until the next day's insolation begins to affect these air layers.

#### TEMPERATURE FLUCTUATIONS AND THEIR VARIATION WITH HEIGHT ABOVE GROUND

During day time when shimmering is going on vigorously, a sensitive temperature measuring element of sufficiently small size will sometimes be in a rising filament of hot air and sometimes in a descending current of cold air, so that its temperature will fluctuate about a mean temperature (5, 16, 17, 18). The mean value of temperature and the range of its fluctuation will both decrease with height above ground. Such measurements with very fine thermo-couples of copper-constantan and a sensitive galvanometer have been carried out at the Central Agricultural Meteorological Observatory at Poona. Fig. 26 shows an example of the results obtained on a clear day at the maximum temperature (6-1-42). Here the height is shown on a logarithmic scale for convenience. Curve MM shows the mean temperature, AA and BB show the mean temperature 'minus' and 'plus' the standard deviation of the 50 readings recorded at each height at 10 second intervals. NN shows the lowest and XX the highest temperature recorded at different levels. The rapid variation with height in the amplitude of the temperature fluctuation is shown clearly by these curves. On plotting the standard deviation against the logarithm of the height it is seen that the points fall practically on a straight line which cuts the height axis at about 170 ft. above ground. This shows that at the maximum temperature epoch the shimmering layer grows to a height of 150 to 200 ft. above ground.

Fig. 27 shows the contrast between the variation of the mean temperature (curves at the top of the diagram) as well as of the short period temperature fluctuations at different heights at 13.00 hrs. and 22.00 hrs. respectively on the 22nd January 1945. These curves

show that under the turbulent conditions in the afternoon the short period fluctuations are very large near the ground, becoming rapidly smaller in amplitude above the 20 cm. level. At night, by 22.00 hours, when the air layers have cooled and stratified with temperature increasing with height (means inversion of temperature and stability of the air layers), the fluctuations are comparatively small at all levels right from the ground surface. It is also interesting to note that well away from the ground at 10 metres or more the fluctuations are small both by day and night.

It may be recorded here that the Poona investigations show that towards the evening the inversion layer starts forming from the upper boundary of the shimmering layer and not from the ground as is usually supposed. Starting at this boundary the inversion layer grows in thickness during the night until the shimmering layer starts growing rapidly after sunrise on the next day and wipes it out. Experiments with captive balloons and electronic methods of recording the thermal structure of these air layers conducted at Poona confirm the above findings and show that the thickness of the inversion layer can be as high as three to four hundred metres in our latitudes.

#### THE EXCHANGE OF WATER VAPOUR BETWEEN THE SOIL AND THE AIR LAYERS ABOVE IT

A considerable amount of work has been done at Poona (8, 13, 16, 39, 41, 42, 44, 45, 48) on this topic. Ramdas and Katti have shown in a series of papers that when soil samples containing only hygroscopic moisture are exposed in the open they lose water by evaporation from the morning up to the maximum temperature epoch in the afternoon. Thereafter, towards the evening, during the night and until sunrise next morning the soil re-absorbs the water vapour from the atmosphere. Once the soil has reached the hygroscopic stage, there is a diurnal variation but no day to day variation in the mean weight of the soil sample. Fig. 28 shows the isopleths of soil moisture (per cent on dry basis) during the period August 1935 to October 1936. In the upper portion of the diagram the rainfall amounts are also indicated in inches. It may be noted that the soil surface dries up rapidly after October, the moisture percentage at the surface being of the order of 5 per cent only during the dry season. This phenomenon of evaporating water vapour into the atmosphere during a part of the day and re-absorbing an equal amount during the rest of the day is actually going on in the soil under natural conditions during the dry season when the top layer of the soil contains only hygroscopic moisture.

Soils vary in their capacity to lose and gain water vapour in the above fashion. Fig. 29 shows the hourly variations in the weights of some typical soils of India when exposed in containers flush with the soil surface at the Central Agri-Met. Observatory at Poona. The mean weight of the soil samples was of the order of 60 gr. spread over 12.6 sq. cm. in glass dishes. The diurnal variation is maximum in the black cotton soils, the red soils having a moderate variation and the alluvial soils only a fifth of the variation shown by the black soils.

There is a complementary phenomenon going on in the air layers near the ground. During day time there is an upward flow of water vapour from the ground with vapour pressure decreasing with height. During night time there is a downward flow of water vapour towards the ground which desiccates the air. The vapour pressure then increases with height above ground. This phenomenon goes on day after day during the dry season,

The variation of vapour pressure with height at the epochs of maximum and minimum temperature is given below for the month of January (average values for 1933-37).

TABLE 9

Height above ground	Vapour pressure in mm. of Hg. at the	
	Maximum temperature epoch	Minimum temperature epoch
0.3 in.	8.6	5.9
1.0 in.	8.2	6.0
3.0 in.	8.0	6.0
6.0 in.	7.8	6.1
1 ft.	7.7	6.2
2 ft.	7.6	6.4
3 ft.	7.5	6.6
4 ft.	7.5	6.8
6 ft.	7.4	7.1
8 ft.	7.4	7.1
10 ft.	7.3	7.4

The investigations on the exchange of moisture between the soil, plant materials, etc., have been continued by Ramdas and Mallik and discussed by them in a series of papers (44, 45, 48).

It may be mentioned that under these conditions only a small fraction of the heat gained by the soil by absorbing solar radiation is used up in evaporating moisture from the soil, but an equal amount of heat is returned to the soil surface when water vapour is re-absorbed.

#### THE THERMAL BALANCE AT THE GROUND SURFACE

The factors which control the thermal (5, 43, 46) balance at the surface of the ground during clear weather may be grouped under (a) Radiation, (b) Convection, (c) Conduction and (d) Evaporation.

*Radiation.*—Visible radiation coming from the sun (30, 37) and the sunlit sky is incident on the ground. The amount of this incoming energy is estimated from solarigraph records. If the albedo of the soil is known, the fraction actually absorbed by the soil surface and converted into heat can be calculated.

Water vapour and other absorbing components of the atmosphere are emitting heat radiation towards the ground both during day and night. The quantity of energy received by the ground is measured with a Pygeometer.

The surface of the ground is continuously emitting radiation as a black body. This is equal to  $\sigma T_s^4$  where  $T_s$  is the surface temperature at any instant. From continuous (hourly) records of  $T$  it is possible to compute the total radiation emitted by the surface during day and night.

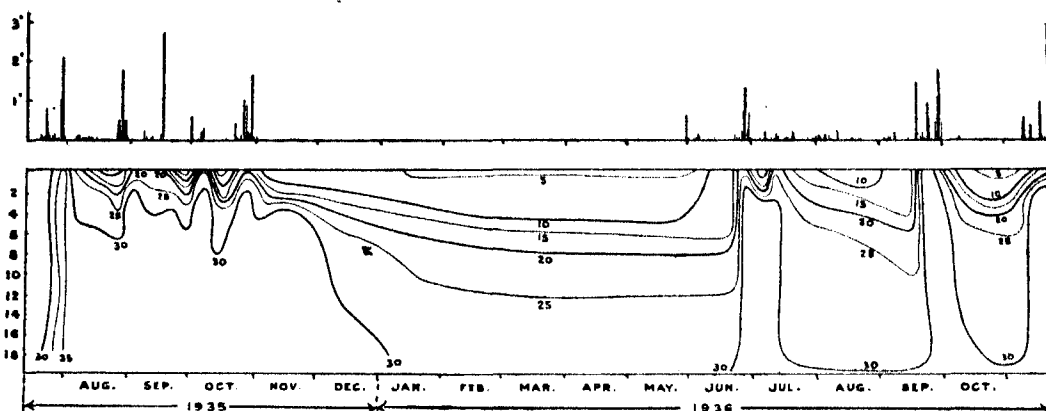


FIG. 28. Seasonal variation of moisture percent. at different depths in the soil. Rainfall in inches is shown in the upper portion of the figure.

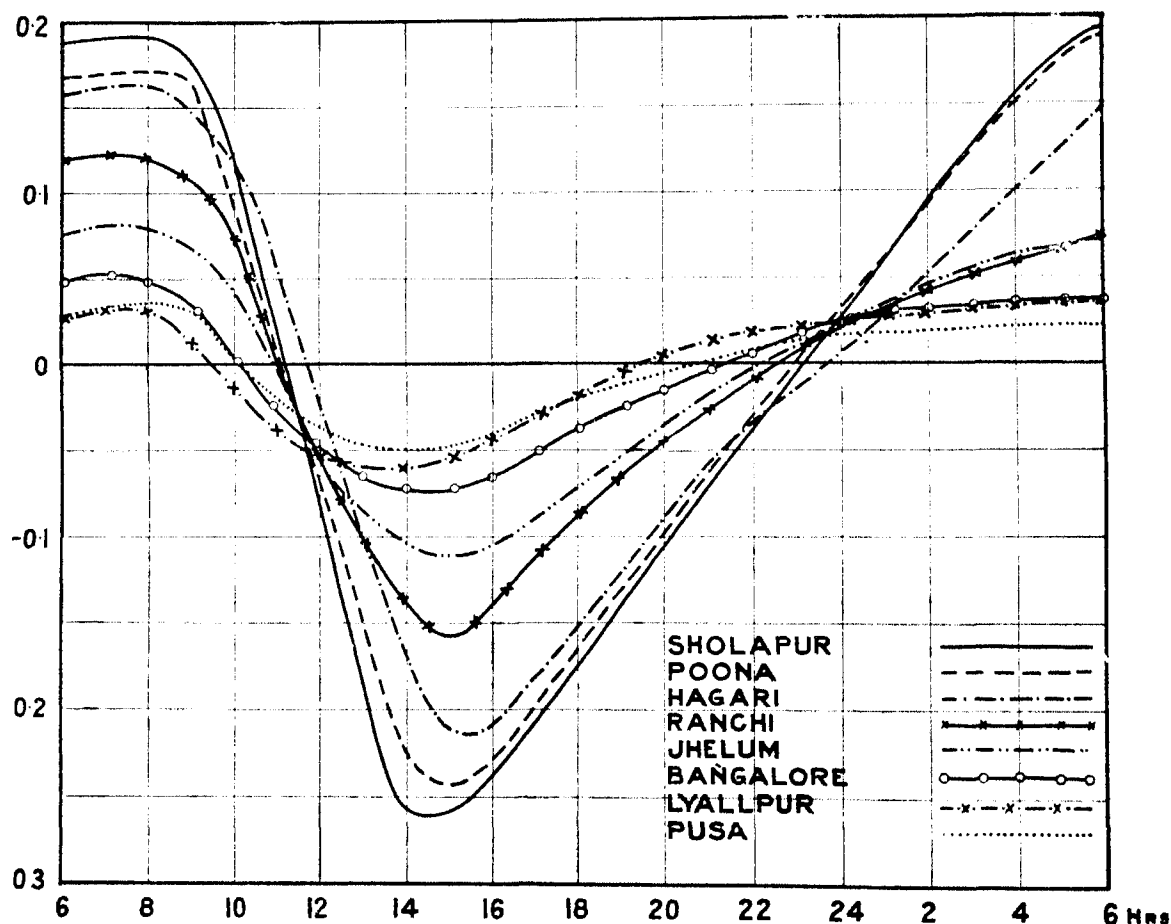


FIG. 29. Diurnal variation in the moisture content of typical soils of India

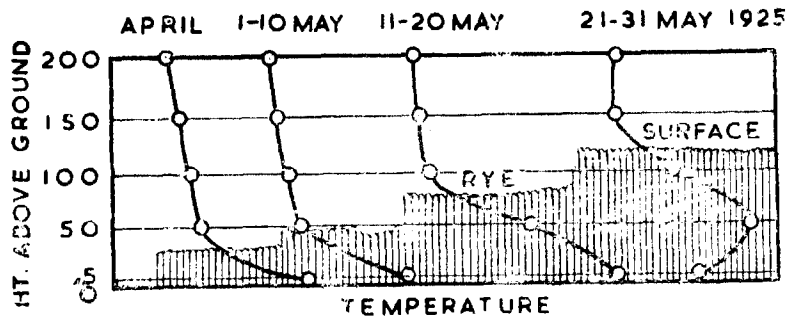


FIG. 30. Daily temperature maxima in a growing cornfield

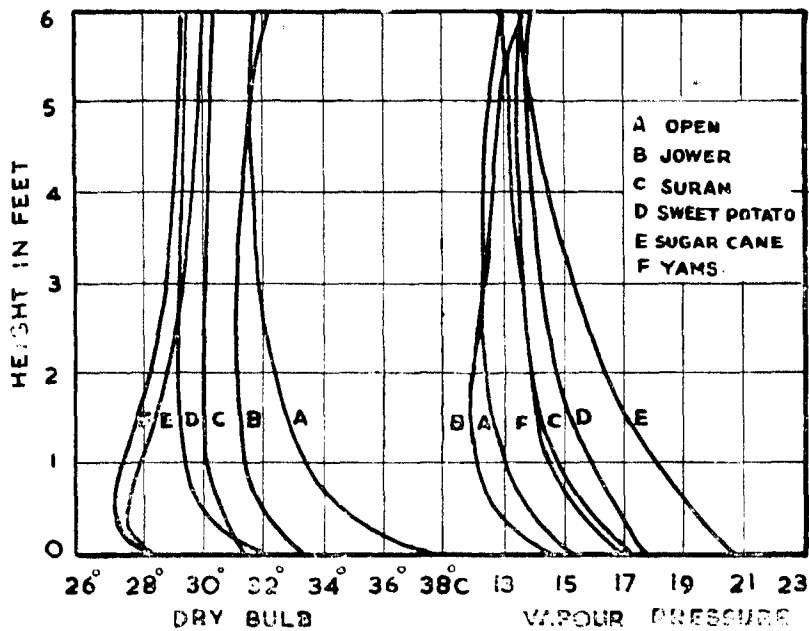


FIG. 31. Variation of dry bulb temperature ( $^{\circ}\text{C}$ ) and vapour pressure (mm. of Hg.) with height above ground in different environments.

**Convection.**—The method of measuring the convective heat loss from the ground has been developed by P. K. Raman (12), working at Poona. This loss mainly occurs during the day time when the surface temperature is appreciably higher than that of the air in contact with it. During night time the loss of heat by convection from the ground is almost negligible.

**Conduction\*.**—During the day time when the soil surface is warmer than the layers below, there is a flow of heat from the surface downwards. During night when the interior of the ground is warmer than the soil surface there is a return flow of heat to the surface. If  $\theta_0$  and  $\theta_1$  are the mean temperatures during an hour at the surface and 1 cm. below it, the heat conducted into the lower layer through the 1st centimetre layer with a mean temperature will be  $K(\theta_0 - \theta_1)$  per unit time per sq. cm. when  $K$  is the soil's heat conductivity. If the unit layer is itself changing in temperature at the rate  $\frac{d\theta_m}{dt}$  the accumulation of heat in the unit layer itself will be  $C \frac{d\theta_m}{dt}$   $C$  being the specific heat of the soil. Therefore, the amount of heat conducted from the soil surface will be  $K(\theta_0 - \theta_1) + C \frac{d\theta_m}{dt}$ . Using appropriate signs for  $\theta_0 - \theta_1$  and  $\frac{d\theta_m}{dt}$  and knowing  $\theta_0$  and  $\theta_1$  and  $\theta_m$  from curves showing the hourly variation of these temperatures, it is easy to compute the heat leaving or arriving at unit area of the soil surface during different hours of the day.

**Evaporation and Condensation.**—The amount of water lost by evaporation from the Poona soil in the day time during the dry season is of the order of 0.03 gr. per sq. cm.; but a more or less equal quantity of water vapour is re-absorbed from the atmosphere during the rest of the day. Thus about 20 gr. cal. of heat are spent in evaporation but about the same quantity is delivered at the surface during the re-absorption.

The Table 10 below gives a statement of the thermal balance at the ground surface at Poona on the 23rd April 1936.

There was a small carry over to the next day, of the order of 11 cal. The above statement is based entirely on experimental determinations of the various factors.

TABLE 10

Gain (gr. cal. per sq. cm.)		Loss (gr. cal. per sq. cm.)	
1. Radiation received from the sun and sunlit sky during day, after correcting for absorption factor at 84 per cent.	655	4. Temperature radiation from ground . . . . .	950
2. Heat radiation from the atmosphere at 0.48 gr. cal. per cm. <sup>2</sup> per minute	691	5. Convective heat loss . . . . .	350
3. Heat gain during absorption of moisture . . . . .	20	6. Heat transfer by conduction (difference between loss by day and gain by night) . . . . .	35
		7. Heat used up in evaporation by day . . . . .	20
Total gain . . . . .	1,365	Total loss . . . . .	1,355

\*For a full discussion of soil temperatures, thermal conductivity of the soil and methods of controlling these partially, please see references 43 and 46.

If the soil is wet, then its temperature will be lower and the factors (i), (iii), (iv), (v) and (vi) will be so affected that more energy will be made available for increased evaporation.

Similarly, if the convective movements in the air layers is higher than usual, then the heat loss by Convection (v) as well as evaporation (vii) will also increase at the expense of the heat losses by radiation and conduction which will be correspondingly reduced.

If we decrease the absorption of solar radiation by covering the soil surface with a thin layer of chalk powder, for example, the gain by radiation will be considerably reduced. At the same time, the surface temperature will also be reduced, so that the heat losses by conduction, convection and evaporation will also be correspondingly reduced. Similarly, if we increase the absorption of solar radiation by covering the soil surface with black charcoal powder, then the heat losses by thermal radiation, conduction and evaporation from the ground surface will also be increased. Thus, by adopting suitable simple devices it is possible to control the thermal balance at a given surface to a sensible extent.

#### THE MICRO-CLIMATES OF PLANT COMMUNITIES

In general meteorology, one is concerned with the climatic conditions in an open, well-exposed, bare and level plot of ground which is situated in an area representative of the particular part of the country. In synoptic meteorology, where one is mainly concerned with weather forecasting, the disturbing influence of the ground surface is avoided as far as possible by recording air temperature, humidity, wind velocity, etc., at some distance above ground, usually 4 ft. and above. The meteorological elements recorded at these weather reporting observatories indicate what is called the general or 'macro climate' of the area. In agricultural meteorology, however, it is precisely the air and soil layers near the ground surface which assume special importance. Investigations carried out at Poona (8, 9, 10, 11, 18, 19, 20, 21, 22,) and at agricultural research stations in India show that if one records the air temperature, humidity, wind velocity, evaporation etc., inside environments like standing crops and orchards and compares these with the observations recorded simultaneously in a neighbouring open space, the micro-climates of these environments show significant and typical deviations from the conditions in the open space.

In Europe, the subject of micro-climatology has made many notable advances in the hands of Schmidt, Geiger and others, particularly in regard to the influence of cities, topography and forest cover (117). The present position of the subject may be briefly summarised here.

##### *Types of Micro-Climate*

*Type A* : During clear weather when winds are feeble and the sun shines on a level stretch of bare soil, insolation and its disposal at the ground surface by conductive, convective, and radiative processes account for the large variations of temperature and humidity with time of day as well as with height above ground.

*Type B* : We may then consider the case in which the surface of the ground is covered with an unirrigated crop. Here the solar radiation falls partly on the foliage which acts like a secondary surface for the disposal of solar energy. The surface of the ground would retain its original importance in proportion to the fraction of solar radiation falling directly in patches wherever the vegetation fails to obstruct its path. This would depend, again,

upon the density of the plant population, the height of the crop and the amount and the vertical and horizontal distribution of the foliage. Thus, the taller the crop, the more abundant its foliage, and the denser the plant population the greater is the deviation of the climate of the crop from that of the 'open'.

*Type C* : We may next consider the influence of a horizontal flow of air on Types A and B. The resulting types may be called AC and BC respectively.

*Type D* : The micro-climate becomes more complex when, in types A, B and C, the soil is irrigated. This gives rise to types like AD, BD, ACD and BCD.

*Type E* : Lastly, there are complicated cases associated with the incidence of cloudiness, rainfall etc., Types like AE, BE, ACE and BCE will fall under this group.

For studying the effect of environment on climate, one of the standard instruments used at Poona is the smaller Assmann psychrometer. The variation of air temperature and humidity with height above ground is studied by taking observations at fixed times daily which include the maximum temperature epoch (2 P.M.) and the minimum temperature epoch (6 A.M.). In the open space of the Central Agricultural Meteorological Observatory at Poona, the observations are taken at various levels from the surface up to 35 ft. above ground with the help of a specially constructed tower. Inside crops, observations are taken up to 6 or 8 ft. above ground and occasionally at higher levels. We may first of all describe some of the main features shown by the psychrometric data in different environments before discussing the wind and evaporation data which have also been recorded recently.

#### *Micro-Climate of the 'Open' during the Winter Season*

*Type. A* : The importance of Type A is obvious as it is the standard type with which to compare the climates of different environments. The winter season at Poona, of which January is typical, is dominated by warming up of the ground due to insolation by day and cooling due to nocturnal radiation. The air movements are feeble varying between 4.5 m.p.h. near the ground to 7.0 m.p.h. at 35 ft. during the afternoon (X epoch) when convective mixing is maximum; during night when the air layers cool and stratify, the mean wind velocities come down very much; at 6 A.M. (N epoch) the velocity is 0.3 m.p.h. near the ground and 1.0 m.p.h. at 35 ft. Long intervals of calm at night are punctuated by occasional light winds of the Katabatic or down-slope type. Table 11 shows the variation with height of the dry bulb temperature in °C, vapour tension in mm. of Hg and the percentage relative humidity at the maximum and minimum temperature epochs during January.

There is an accumulation of heat at and near the ground in the afternoon (2 P.M.). The maximum temperature rises to 51.6°C at the surface and decreases rapidly at 30:1 °C at a height of 1 ft. and then gradually to 27.0 °C at 35 ft. On the other hand, at night, owing to nocturnal cooling, the thermal structure of the air layers is very different. Even at 6 A.M. (minimum temperature epoch), there is a thin but feebly convective layer about 1 ft. in thickness within which the temperature decreases with height as during day time but less conspicuously (a remnant of the convective layer characteristic of day time).

Above this layer we have the stratified inversion layer extending upwards beyond 35 ft. In the inversion layer the coldest air ( $10.3^{\circ}\text{C}$ ) is at the level of 1 foot above ground and the temperature increases with height up to a few hundred feet (as is shown by captive sounding balloon records). At 35 ft. the temperature is  $13.4^{\circ}\text{C}$ , about  $3^{\circ}\text{C}$  warmer than at 1 ft. The inversion layer persists up to about 10 A.M. when convection sets in and rapidly destroys it.

If we consider the difference between the 2 P.M. (X) and the 6 A.M. (N) observations the 'diurnal range', as it is called, is as high as  $40.8^{\circ}\text{C}$  at the surface; it decreases rapidly to  $19.8^{\circ}\text{C}$  at 1 ft. and thereafter slowly to  $13.6^{\circ}\text{C}$  at 35 ft.

The vapour pressure indicates the amount of water vapour present in the air layers, one cubic metre of air in which the pressure of water vapour is 1 mm. of Hg. containing very nearly 1 gr. of precipitable water vapour. If the actual vapour pressure is x mm. the water content would be x grs. per cubic metre.

TABLE 11 (January)

Height	D.B. Temperature $^{\circ}\text{C}$			Vapour pressure in mm. of Hg.			Humidity per cent.		
	X	N	X-N	X	N	X-N	N	X	N-X
0-Tg."	51.6	10.8	40.8						
0.3"	34.6	10.9	23.7	10.9	8.0	2.9	78	29	49
1.0"	33.8	10.6	23.2	10.3	7.8	2.5	77	29	48
3"	31.9	10.5	21.4	9.8	7.7	2.1	77	29	48
6"	30.9	10.4	20.5	9.3	7.7	1.6	77	29	48
1 ft.	30.1	10.3	19.8	9.0	7.7	1.3	78	30	48
2 ft.	29.4	10.5	18.9	8.8	7.8	1.0	78	30	48
3 ft.	28.8	10.7	18.1	8.6	7.9	0.7	79	31	48
4 ft.	28.4	10.9	17.5	8.6	8.4	0.2	79	31	48
6 ft.	28.1	11.3	16.8	8.6	8.4	0.2	79	31	48
8 ft.	27.7	11.6	16.1	8.5	8.5	0.0	80	31	49
10 ft.	27.5	11.9	15.6	8.4	8.7	-0.3	80	32	48
15 ft.	27.3	12.2	15.1	8.3	9.0	-0.7	81	31	50
20 ft.	27.0	12.6	14.4	8.2	9.1	-0.9	81	32	49
25 ft.	26.9	12.9	14.0	8.1	9.2	-1.1	80	31	49
30 ft.	26.9	13.1	13.8	8.1	9.2	-1.1	79	31	48
35 ft.	27.0	13.4	13.6	7.9	9.3	-1.4	79	31	48

It has been shown already that during the day when insolation is present the vapour pressure decreases with height above ground; during night until insolation begins next morning the vapour pressure increases with height above ground. Thus the 2 P.M. and 6 A.M. observations would be more or less typical of the day and night conditions respectively. Table 11 shows that at 2 P.M. the vertical gradient of vapour pressure favours an upward flow of water vapour, whereas at 6 A.M. this flow will be towards the ground. These movements of water vapour are to a large extent controlled by the hygroscopic property of the soil surface, which is very marked in the case of the black cotton soils of India.

As regards the relative humidity, the variation with height is small compared to the diurnal variation which is nearly 50 per cent as is shown by the differences between the morning and the afternoon values in the last column of Table 11.

*Micro-Climate of the 'Open' during Summer*

*Type AC:* Type AC stands for type A as modified by winds which are stronger than in winter. These conditions prevail during March, April and May in the Deccan. Insolation by day is stronger than during winter so that convective winds of the forenoon and afternoon are also stronger than during the winter. Again, owing to the proximity to the Arabian Sea, the westerly sea-breeze\* comes inland as a layer of about  $\frac{1}{2}$  Km. in thickness and replaces the drier land air temporarily during the afternoon and night and is later diluted with the land air by the convective winds of the next day. In April which is a typical summer month, the wind velocity varies from 6 to 8 m.p.h. in the afternoon and from 0.8 to 1.8 m.p.h. in the morning between ground level and 35 ft. respectively. Table 12 gives the mean temperature and humidity data at various levels above ground at 2 P.M. and 6 A.M. during the month of April. In the afternoon the temperature goes up to  $64.1^{\circ}\text{C}$  at the surface, decreases rapidly to  $40.1^{\circ}\text{C}$  at 1 ft. and thereafter gradually to  $35.6^{\circ}\text{C}$  at 35 ft. Owing to increased air movements at night, the feeble convective layer, up to 1 ft., of the winter season is wiped out, the inversion starting right from the ground under these circumstances and the effect of nocturnal cooling is diluted over a thicker layer of the atmosphere so that the inversion rate is less than it is in winter, particularly in the lower layers. The temperature falls to  $18.7^{\circ}\text{C}$  at the surface in the early morning, the corresponding value at 35 ft. being  $21.5^{\circ}\text{C}$ . The diurnal range is as high as  $45.4^{\circ}\text{C}$  at the surface, decreases rapidly to  $20.5^{\circ}\text{C}$  at one ft. and slowly thereafter to  $14.1^{\circ}\text{C}$  at 35 ft.

TABLE 12 (April)

Height	D. B. Temperature $^{\circ}\text{C}$			Vapour pressure in mm. of Hg.			Humidity per cent.		
	X	N	X-N	X	N	X-N	N	X	N-X
0-Tg.	64.1	18.7	45.4						
0.3"	44.0	19.8	24.2	8.7	9.2	-0.5	51	13	38
1.0"	42.7	19.6	23.1	8.2	9.0	-0.8	51	13	38
3"	41.9	19.6	22.3	7.8	8.9	-1.1	50	13	37
6"	40.9	19.6	21.3	7.5	9.0	-1.5	51	13	38
1 ft.	40.1	19.6	20.5	7.2	9.1	-1.9	51	13	38
2 ft.	39.3	19.6	19.7	7.1	9.4	-2.3	53	14	39
3 ft.	38.5	19.7	18.8	6.8	9.6	-2.8	54	14	40
4 ft.	37.9	19.9	18.0	6.7	9.8	-3.1	54	14	40
6 ft.	37.4	20.1	17.3	6.5	10.1	-3.6	56	14	42
8 ft.	36.9	20.3	16.6	6.5	10.4	-3.9	57	14	43
10 ft.	36.5	20.4	16.1	6.3	10.6	-4.3	57	14	43
15 ft.	36.2	20.6	15.6	6.2	10.7	-4.5	57	14	43
20 ft.	35.8	20.9	14.9	6.2	10.7	-4.5	56	14	42
25 ft.	35.8	21.1	14.7	6.3	10.8	-4.5	56	15	41
30 ft.	35.6	21.3	14.3	6.4	10.8	-4.4	56	15	41
35 ft.	35.6	21.5	14.1	6.7	10.7	-4.0	54	15	39

\*The time of onset is as late as 19.30 or 20.00 hrs. I. S. T. on some days in late winter (February) but the sea-breeze comes earlier and more frequently as the summer approaches. In April, May and June, the time of onset is often as early as 14.00 or 15.00 hrs. I.S.T.

The vapour pressure decreases with height by day and increases with height at night as in January but there is also a general increase in vapour pressure in the evening due to sea-breeze which comes in the afternoon and stagnates over the country until next morning as is shown by the 6 A.M. (N) observations; this more humid air is later mixed up with the drier atmosphere when the convective winds are set up by insolation. The relative humidity increases slightly with height at the X and N epochs but the diurnal variation from X to N epochs is conspicuous at all levels.

*Micro-climate during the South-west Monsoon Season with Cloudy, Rainy and Windy Weather*

*Type ACE:* With the onset of the south-west monsoon the climate changes from the continental type (AC) to one of the maritime type ACE with continuous and vigorous air movement day and night and cloudy and wet weather. There is very little insolation by day and nocturnal cooling is negligible. In July, the mean wind velocity ranges in the afternoon from 7 m.p.h. near the ground to 15 m.p.h. at 35 ft.; even in the morning the values come down only to 4.5 m.p.h. and 10.2 m.p.h. respectively. Table 13 gives the mean air temperature, vapour pressure and relative humidity in July at different levels and at the X and N epochs. The air temperatures vary in the afternoon from 32.0°C at the surface to 25.3°C at 35 ft. and in the early morning from 21.8°C at the surface to 22.9°C at 35 ft. The diurnal range is only 10.2°C at the surface and 2.4°C at 35 ft.

In contrast to the summer conditions, the vapour pressure in July is 21.1 mm. and 18.3 mm. at the surface and at 35 ft. respectively in the afternoon; in the early morning also the variation with height is similar though smaller than that during day, the values at the surface and at 35 ft. being 18.4 mm. and 17.9 mm. respectively. The diurnal range of vapour pressure (X-N) varies from 2.7 at the surface to 0.4 at 35 ft. The relative humidity decreases with height at both the X and N epochs; the values at the N epoch are about 10 per cent lower than those at the X epoch. During the monsoon, the soil surface is always moist and often saturated with water so that the above results are easily understood.

TABLE 13 (July)

Height	Dry bulb temperature in °C			Vapour pressure in mm. of Hg.			Humidity per cent.		
	X	N	X-N	X	N	X-N	N	X	N-X
0-Tg.	32.0	21.8	10.2						
0.3"	27.1	22.7	4.4	21.1	18.4	2.7	89	79	10
1.0"	27.0	22.6	4.4	20.8	18.4	2.4	89	79	10
3"	26.9	22.6	4.3	20.4	18.4	2.0	89	78	11
6"	26.8	22.6	4.2	20.1	18.3	1.8	89	77	12
1 ft.	26.6	22.6	4.0	19.8	18.3	1.5	89	77	12
2 ft.	26.5	22.6	3.9	19.6	18.2	1.4	89	77	12
3 ft.	26.3	22.7	3.6	19.4	18.2	1.2	88	76	12
4 ft.	26.1	22.7	3.4	19.2	18.2	1.0	88	76	12
6 ft.	26.0	22.8	3.2	19.0	18.1	0.9	87	76	11
8 ft.	25.8	22.8	3.0	18.9	18.1	0.7	87	76	11
10 ft.	25.6	22.8	2.8	18.7	18.0	0.7	87	76	11
15 ft.	25.5	22.9	2.6	18.6	18.0	0.6	86	76	10
20 ft.	25.5	22.9	2.6	18.5	18.0	0.5	86	76	10
25 ft.	25.4	22.9	2.5	18.4	18.0	0.4	86	76	10
30 ft.	25.4	22.9	2.5	18.3	17.9	0.4	86	76	10
35 ft.	25.3	22.9	2.4	18.3	17.9	0.4	85	76	9

*Micro-Climates of Crops (19)*

*Types B and BD:* As mentioned by Geiger (117) the influence of vegetation on micro-climate varies with the height and density of the vegetation and it is possible to distinguish four stages.

*Stage 1:* The plants have just germinated and the growth is small both in height and density so that the bare ground is covered only to a small extent. The micro-climate varies little from that above the bare ground. In this early stage the small plants have to withstand the extremes of temperature characteristic of Type A and the mortality is high. The utility of taller plants and shade trees in reducing such mortality is shown by the great care taken in plantations of tea, cardamoms, etc., for providing a network of shade trees.

*Stage 2:* The plants reach the stage of 'lateral stoppage'. By spreading laterally while growing vertically, they cover the ground more uniformly than in Stage 1. The micro-climate is now appreciably affected by the vegetation. The diurnal range of temperature is reduced and the air layers up to the height of the vegetation and the soil below are more humid than in Stage 1. Owing to these more favourable conditions young plants often show a sudden spurt of growth in height at the time when the stage of lateral stoppage is reached.

*Stage 3:* In the first two stages the seat of the diurnal transfer of heat was at the ground surface. When plants grow close together and attain heights there will be interspace between the surfaces of the ground and of the vegetation. If the crown of the plants forms an effective canopy completely shutting off insolation from the ground, it is the former which absorbs solar radiation during the day and radiates heat during night. Woeikof calls it the 'external active surface' (118). It must be remembered, however, that the plant canopy does not form a simple surface like the ground but has necessarily a certain vertical range in its action. Between the external active surface and the ground surface there is a sheltered region in which, owing to the action of the plants, there is great calm, high humidity, protection from radiation, moderate temperatures by day and greater warmth than in the 'open' at night.

*Stage 4:* In this case the plants have grown into a tall forest with three zones :

1. the stem region in which there is some possibility of air motion
2. the foliage region which forms a barrier to air movements
3. the air space above the foliage and merging into the free atmosphere

In stages 3 and 4, if the plant density is low, there will be gaps through which sunshine will be able to reach the ground. We then have two active surfaces, *viz.*, the ground and the upper boundary of the plant cover.

Fig. 30 is a diagram given by Geiger showing the transition from the second to the third stage in the variation of temperature with height in a winter rye field at Munich. The daily temperature maxima obtained from Six's thermometers are averaged for the different seasons and the height of the crop corresponding to these maxima are represented in the diagram. In April, the local temperature maximum was at the surface although the surface was covered with the young rye plants up to a height of several cms (Stage 2). Towards the end of May, however, the maximum had left the ground surface and the highest temperatures were recorded at about 50 cms. above ground, the height of the crop itself being 120 cms.

While dealing with crops one should compare the micro-climate of the crop with that of the open. In India the 'rabi' or 'winter' crops which are unirrigated would fall under Type B while those which are irrigated would come under Type BD, so long, as the skies are clear and the winds are light. The winter season at Poona gives rise to these two types\*.

Table 14 gives the mean dry bulb temperature in °C and the vapour pressure in mm. of Hg. at various levels up to 6 ft. in the 'open' and 'inside' of sugarcane, jowar, cotton and tobacco crops\*\* growing at Poona near the Central Agricultural Meteorological Observatory in December 1936. The data are given both for the maximum temperature (X) and the minimum temperature (N) epochs. An inspection of this table will show that the systematic deviations of the crop climate from that of the 'open' space are most marked in the case of an irrigated tall crop like sugarcane (Type BD). There are also significant though smaller deviations when the crop is tall but unirrigated, e.g., in jowar. A short crop does show deviations, though small, if there is sufficient foliage to allow the formation of a local climate underneath, e.g., in tobacco. In the case of another short crop like cotton the deviations from the climate of the 'open' are not significant except, later in March when sufficient foliage develops. In general, the air inside a crop contains more moisture than outside. Further, during night, the temperature inside a crop is warmer than that in the 'open'.

TABLE 14

Height	X Epoch					N Epoch				
	Open	Sugar-cane	Jo-war	Cot-ton	To-bacco	Open	Sugar-cane	Jo-war	Cot-ton	To-bacco
<i>Dry Bulb °C</i>										
0.3"	33.6	24.9	31.2	32.6	34.6	9.0	10.5	9.9	8.8	8.7
1"	32.0	25.0	30.7	31.9	33.5	8.9	10.4	9.9	8.8	8.7
3"	31.4	25.1	30.6	31.5	32.4	8.8	10.3	9.8	8.8	8.7
6"	30.9	25.4	30.5	31.0	31.9	8.9	10.2	9.8	9.0	8.7
1 ft.	30.4	25.9	30.3	30.5	31.2	9.0	10.1	9.7	9.1	8.8
2 ft.	30.0	26.4	30.1	30.1	30.6	9.2	10.1	9.7	9.2	9.0
3 ft.	29.4	26.9	29.7	29.5	30.0	9.4	10.0	9.5	9.4	9.2
4 ft.	29.0	27.1	29.4	29.2	29.5	9.7	10.1	9.8	9.5	9.5
6 ft.	28.6	27.4	29.1	28.9	29.0	9.9	10.1	9.9	9.7	9.6
<i>Vapour pressure</i>										
0.3"	9.0	13.6	10.1	9.7	9.9	7.1	8.8	8.0	6.9	7.3
1"	8.8	13.1	9.9	9.5	9.4	7.2	8.7	8.0	6.9	7.3
3"	8.6	12.5	9.6	9.2	8.9	7.2	8.6	7.9	7.0	7.3
6"	8.4	12.0	9.5	8.9	8.7	7.3	8.6	7.9	7.1	7.3
1 ft.	8.3	11.4	9.3	8.7	8.6	7.4	8.5	7.9	7.2	7.4
2 ft.	8.1	10.8	9.0	8.6	8.4	7.6	8.4	8.0	7.3	7.5
3 ft.	8.0	10.4	8.9	8.5	8.2	7.7	8.4	8.0	7.5	7.5
4 ft.	8.1	10.1	8.7	8.4	8.2	7.9	8.4	8.1	7.6	7.7
6 ft.	8.0	9.9	8.9	8.2	8.2	8.0	8.4	8.1	7.7	7.8

\*During the monsoon with high winds, cloudy skies and rainy weather the change with environment will be small, i. e., type BE will approach type AE.

\*\*The heights of these crops were 9ft., 7ft., 3½ft. and 1½ ft. respectively.

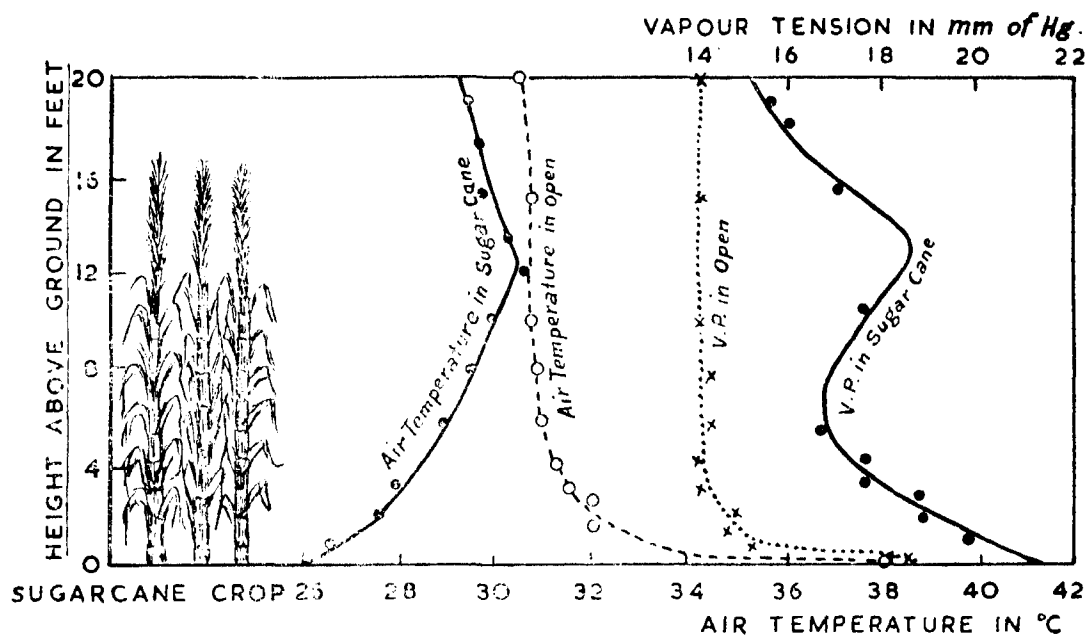


FIG. 32. Micro-climate of sugarcane

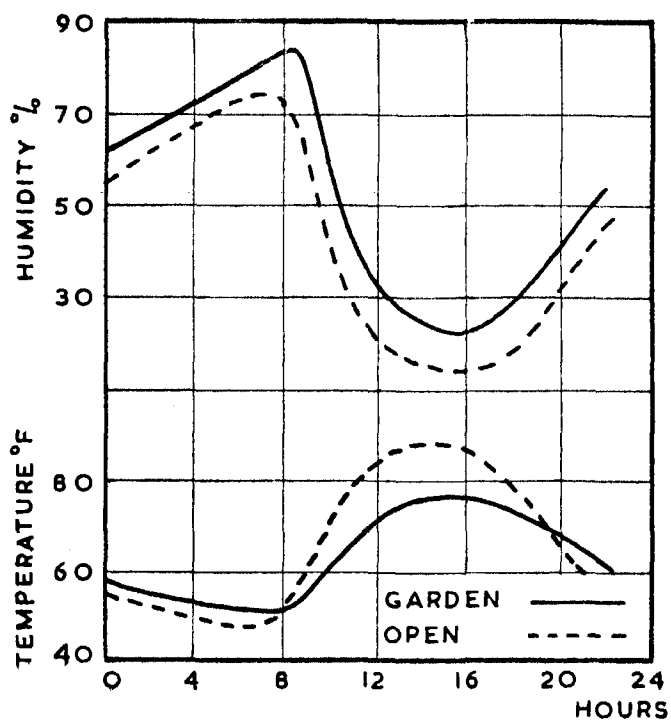


FIG. 33. Diurnal variation of air temperature (°F) and relative humidity at 4 ft. above ground in the open and inside vine-yard at Nasik (January)

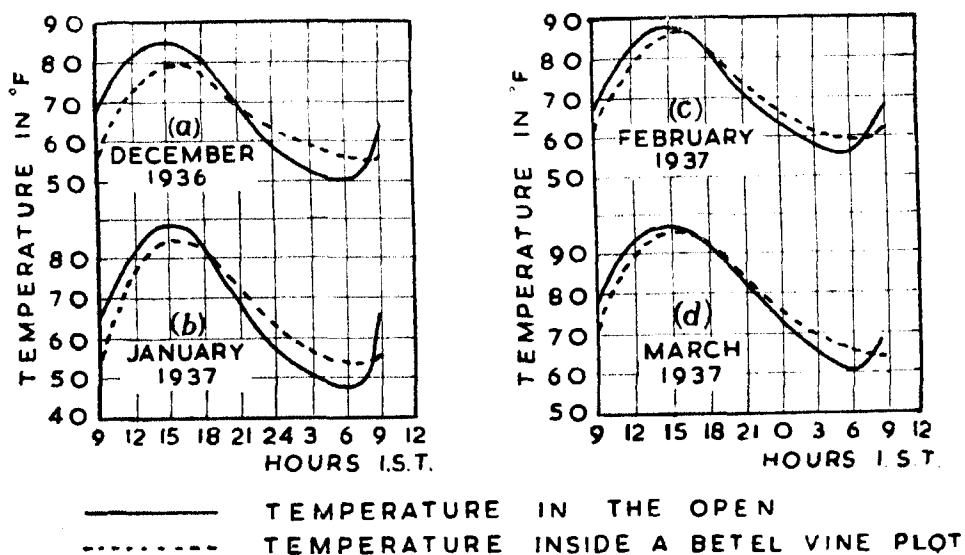


FIG. 34. Mean hourly variation of air temperature

Fig. 31 shows curves of air temperature and vapour pressure at 2 P.M. on the 9th October 1934 in a number of environments at different levels above ground. Here *Jowar*, (*Andropogon sorghum* Brot.), sugarcane and yams (*Dioscorea batatas* Dcne), are tall crops, the first alone being unirrigated; suran (*Amorphophalus campanulatus* Blume), and sweet potato are short crops with a certain amount of foliage spreading laterally. The heights of the crops were 3 ft., 4ft., 7 ft., 2 ft., and 2 ft. respectively. It is interesting to see the variation of temperature and vapour pressure with environment. We have at one end the curve A representing the extreme conditions in the open with a rapid fall of temperature with height. At the other end we have the sugarcane and yam fields, both irrigated, with temperature low near the ground and rising with height as in a nocturnal inversion.

### *The Micro-Climate of the Sugarcane Crop*

The micro-climate of sugarcane is of special interest. When fully developed, this crop has a form of canopy. Conditions inside sugarcane would therefore give some idea of what may be expected inside a forest with canopy.

It is very interesting to compare the conditions in the 'open' at the maximum temperature epoch with those inside sugarcane in flower. The over-all height of the crop is then of the order of 14 to 15 ft. in November at Poona (cf. Fig. 32). The stems are almost bare from ground up to 4 ft.; above this the foliage increases rapidly and extends up to about 11½ ft. The crop is crowned by flowers from 11½ ft. to 14½ ft. The wind-break effect of the crop *i.e.*, its ability to reduce air movements, may be expressed as shown below :

$$\frac{\text{Velocity in the open} - \text{Velocity inside crop}}{\text{Velocity in the open}} \times 100$$

This 'breaking' effect is 90 per cent. or more in the height interval from 4 to 14½ ft. where the foliage is thick. The crop forms a dense stand with the foliage forming an effective canopy except for very small openings through which sunshine can reach the ground in patches. While the ground is the 'active' surface in the open, ('active' because it is the source of heating by day and cooling by night for the adjacent air and soil layers), in a sugarcane crop the ground is much less active, whereas the canopy which has a certain vertical extent is more 'active'. Under these conditions, in marked contrast to the "open" air, the air temperature inside the crop (Fig. 32) at the maximum temperature epoch increases with height, forming an inversion. Thus, we have relatively stable conditions during the day inside the crop (such conditions prevail in the open only at night due to radiative cooling). As may be expected, the pressure of water vapour is maximum near the wet surface of the ground, decreases with height up to 7 ft., and increases from 7 to 13 ft. owing to the water vapour transpired by the foliage. These details are brought out in Fig. 32 where the dotted curves refer to the 'open'. The lowering of air temperature, the development of stability (inversion) and increased humidity inside the crop may be noted. Above the crop, free air conditions prevail. Inside tropical or sub-tropical forests with 'canopy' the conditions are more or less as described above.

Observations on the movements of smoke inside a sugarcane field during day time show that, as compared to the turbulent conditions outside, the air movement or turbulence inside the crop is negligible. It is not completely absent but very suppressed or subdued. The random movements are very sluggish, the horizontal drift being more in evidence. The day time inversion inside a plant community with a canopy is a 'forced' inversion,

to coin a new phrase, due to heating of the canopy by solar radiation to a greater extent than the ground which is practically shaded. The air layers in an environment showing 'forced inversion' will not be as stratified and extremely quiet as in the 'static inversion' layer which develops in the 'open' during night, when the general air movement is itself small. The 'wind-break' effect of the crop or forest combined with the heating of a continuous canopy are responsible for the forced inversion inside the crop or forest.

Gadre (22) working at Poona has discussed a complete Micro-climatic survey of a sugarcane field at Poona. He has shown that (a) the crop tends to develop its own local or micro-climate after 3 months' growth and (b) the open climate changes into the crop's climate within 3 row-widths from the border.

#### *Climate of a Vineyard (Type B changing to BD when irrigated)*

Fig. 33 shows the mean hourly variation of air temperature in °F and the percentage relative humidity in the 'open' and inside a vineyard at Nasik at a level of 4 ft. above ground during the period 6th January to 2nd March 1935. The data were obtained from thermographs and hygrographs exposed in Stevenson screens kept in these two environments. The air temperature is higher in the 'open' during day time and lower at night than that inside the garden. The epochs of maximum and minimum temperature occur in the garden some time later than in the 'open'. The percentage humidity is higher in the garden than in the 'open' at all hours of the day. The epoch of maximum and minimum saturation occur in the garden a little later than in the 'open'.

#### *Effect of Wind on the Micro-climate of a Betel-vine (Piper betel Linn.)*

*Type BCD:* We may now give an example of the effect of wind on the micro-climate. At Poona, in winter, when the air movements are feeble, the deviations from the climate of the 'open' are large as mentioned earlier. With the advance of the season the air movement becomes stronger gradually. The effect of the increase in wind velocity on the micro-climate of a crop of betel-vine (periodically irrigated) is shown by the Fig. 34(a), (b), (c) and (d). These show the mean hourly variation of air temperature (measured by thermographs exposed inside Stevenson screens) in °F, at 4ft. above ground in the open and inside the betel-vine plot, in December 1936 and January, February and March 1937. As in Fig. 33 the temperature in the open is higher during day and lower during night than inside the crop, the X and N epochs in the crop showing a lag, as is to be expected. In December the diurnal range of temperature is 36°F in the open and 27°F inside the crop. In January also the curves show similar variations. In February, when the winds increase in velocity the curves begin to approach each other and by March when the winds are still stronger the temperatures inside the crop and outside approach still closer. Thus, the effect of strong air movement during clear weather is to decrease the difference in the temperatures of the two environments. In this particular instance we have an example of the clear weather Type BD changing to Type BCD under conditions where little or no sunshine actually reached the surface of ground owing to the presence of dense vegetation.

#### *Type BCE changing gradually to BD*

We have another example shown in the curves of Fig. 35(a), (b), (c), (d), (e) and (f). These show the hourly variation of air temperature (at Poona) at 4 ft. in the 'open' and inside a banana plantation, where the rows of plants and the plants in a row

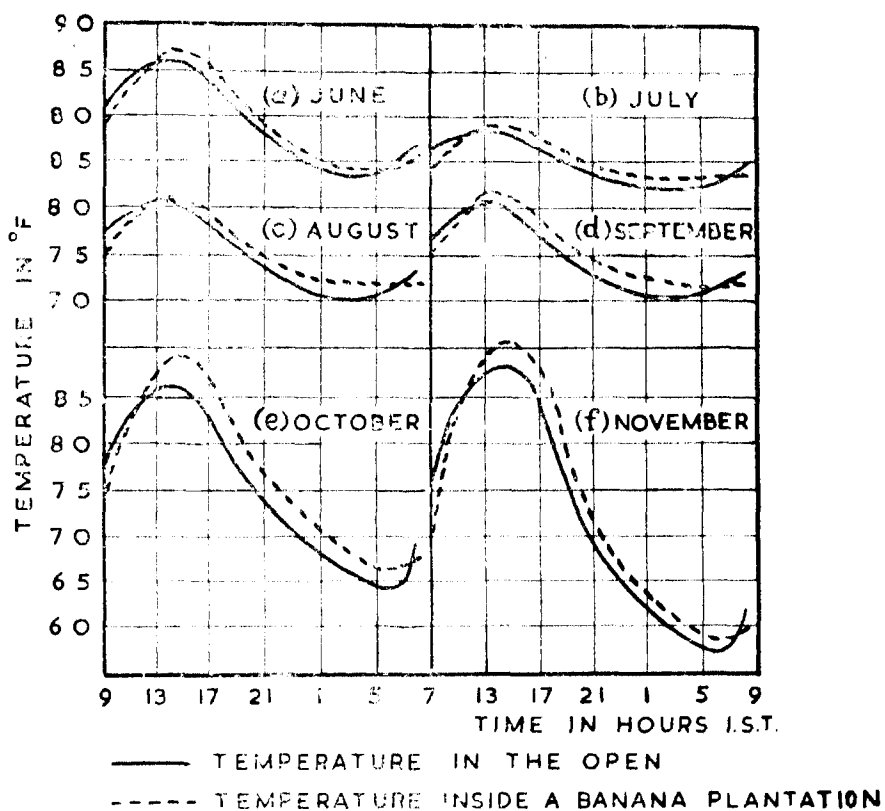


Fig. 35. Mean hourly variation of air temperature

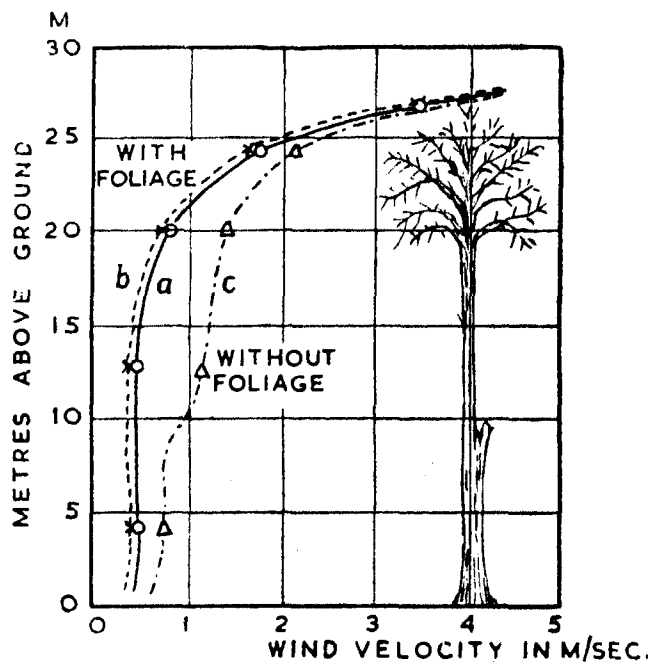


Fig. 36. Air motion in the interior of an oak forest

MONTHS	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER
ASSAM.	0.95	1.49	2.71	2.73	5" 2.90	2.61	2.74	2.87	2.49	2.23"	1.42	1.07
BENGAL.	2.70	3.24	5.47	6.09	10" 5.39	3.51	2.97	2.61	2.42	3.00	2.75	2.49
ORISSA.	4.96	5.60	10.11	10.86	11.47	9.60	4.53	3.87	3.48	4.8	4.44	4.12
CHOTA NAGPUR.	4.64	5.14	10.26	14.48	13.92	6.54	3.19	2.54	3.57	5.33	4.71	4.84
BIHAR.	2.42	3.40	7.58	10.29	8.97	6.33	3.59	3.24	3.77	4.29	3.12	2.32
U.P. EAST.	2.56	3.06	7.73	12.14	15" 14.79	9.59	4.74	3.50	4.11	5.27	3.31	2.26
U.P. WEST.	4.57	5.47	10.89	16.81	20" 21.83	15.78	7.20	4.73	6.47	9.54	6.61	4.60
PUNJAB E.&N.	2.34	2.40	5.15	8.75	13.69	12.91	7.57	5.04	5.67	6.22	3.03	2.54
PUNJAB S.W.	2.57	2.88	5.24	8.79	13.24	14.76	10.42	7.84	7.59	5.52	4.35	2.91
N.W.F. PROVINCE.	2.17	2.35	4.03	7.11	11.72	13.05	8.34	5.98	5.97	5.55	3.03	2.17
BALUCHISTAN.	1.27	1.57	3.07	4.83	10" 7.41	9.21	8.59	7.22	5.82	4.06	2.61	1.58
SIND.	5" 5.54	5.83	9.60	11.88	15" 15.29	13.88	12.29	9.25	8.37	9.12	6.95	6.04
RAJPUTANA W.	5" 5.40	6.68	11.37	15.73	20" 20.12	17.49	12.23	10.90	8.83	11.55	8.11	6.34
RAJPUTANA E.	4.65	5.29	9.61	15.54	19.96	16.11	7.47	5.58	7.53	9.42	6.24	4.65
GUJARAT.	8.46	7.83	11.46	14.01	20" 16.73	13.04	8.42	6.92	7.72	8.74	9.53	8.44
C.I. WEST.	6.36	7.08	14.32	24.30	25.82	16.29	7.63	5.61	6.42	9.46	7.29	6.01
C.I. EAST.	3.94	5.01	10.51	17.07	25.67	15.21	5.38	3.75	4.29	6.08	4.56	3.63
BERAR.	9.05	9.13	15.35	17.73	21.79	16.77	4.59	3.81	4.11	8.37	8.64	8.37
C.P. WEST.	5.63	7.10	12.06	15.24	22.84	10.83	4.73	3.82	4.81	6.73	5.97	5.32
C.P. EAST.	5.16	6.17	12.01	16.00	22.34	11.11	4.58	3.76	4.09	4.51	4.85	4.49
KONKAN.	5.54	5.53	7.08	10" 7.93	7.98	5.23	4.91	4.06	2.71	3.61	5.20	6.14
BOMBAY DECCAN.	10" 11.17	11.45	17.57	20" 18.94	15.54	8.87	6.04	5.44	4.82	6.74	9.41	9.24
HYDERABAD N.	14.76	15.37	22.88	29.13	21.92	10.83	5.92	5.15	5.82	10.88	12.00	10.91
HYDERABAD S.	10" 8.19	9.53	14.03	16.07	19.30	12.25	7.52	7.57	6.15	7.76	7.46	7.02
MYSORE.	5" 6.86	6.93	9.84	7.99	7.71	5.24	4.07	4.06	5.72	4.22	4.85	5.44
MALABAR.	5" 5.01	4.36	5.38	5.58	4.88	2.46	2.55	2.68	2.77	2.61	2.84	4.15
MADRAS S.E.	4.88	5.57	6.97	10" 6.72	8.11	9.24	8.14	6.63	5.72	4.33	3.87	4.48
MADRAS DECCAN.	5" 6.32	7.98	13.21	15" 16.08	17.76	12.57	9.08	8.46	6.42	5.86	5.16	4.96
MADRAS C.N.	5.91	6.16	8.48	7.92	8.34	7.20	5.24	4.11	4.00	5.18	5.93	5.78

FIG. 37. Mean monthly evaporation in different subdivisions of India

were 6 ft. apart. The plants were about 6 ft. in height. The temperature records were obtained from thermographs during the months of June, July, August, September, October and November 1937.

The weather during June to September is of type BCE, with mainly overcast skies, precipitation at intervals and moderate to strong winds. In October, the weather improved but there were a few thunder-storms. November, a clear month, would bring about the micro-climate of Type A in the 'open' and Type B changing to BD in the banana plantation during irrigation. One notable difference between the banana plantation and the betel-vine crop referred to earlier is that in the former sunshine falls on the ground in the interspace between plants while this does not happen in the latter. There is a certain accumulation of heat in the banana plantation which is not dissipated at the same rate as in the 'open', owing to the wind-break effect of the crop and the neighbouring trees. This localisation of warmth during the afternoon was small in June and July when the skies were overcast and the average wind velocity was 8 miles per hour. Later, the wind decreased from 7.8 m.p.h. in August (cloudy) to 2.0 m.p.h. in October (occasionally cloudy, mainly clear). In November with no rain and little cloudiness, although the wind velocity was as low as 1.3 m.p.h. the excess of temperature inside the crop was smaller than in October, owing presumably to the decrease in the intensity of insolation with the approach of winter.

#### *Effect of Vegetation on Wind Velocity (15)*

Having examined the effect of vegetation on the air temperature and humidity, we may now pass on to the wind-breaking effect of different environments.

For studying in detail the vertical structure of the wind velocity and its variation with time of day and with environment the handy portable hot-wire anemometer is an ideal instrument, particularly when observations are desired at very short height intervals close to the ground. Measurements were made at Poona with this instrument at heights of 3", 6", 1', 2', 3', 4', 6', and 8' in the 'open' and in different crops. During the last few years a general survey has been made inside a number of crops. Table 15 gives the mean velocity in miles per hour during the period of 17th November to 11th December 1937 in the "open" and inside jowar, suran (Elephant foot) and sugarcane crops.

TABLE 15. MEAN WIND VELOCITY IN MILES PER HOUR FROM 17-11-37 TO 11-12-37

Height above ground	Minimum temperature epoch				Maximum temperature epoch			
	Open	Jowar	Suran	Sugar-cane	Open	Jowar	Suran	Sugar-cane
3 in.	.49	.38	.31	.31	2.37	.78	1.25	.38
6 in.	.58	.36	.34	.31	2.73	.65	1.28	.40
1 ft.	.47	.34	.25	.29	2.91	.76	1.32	.45
2 ft.	.60	.25	.27	.25	2.98	.72	1.81	.38
3 ft.	.78	.25	.34	.25	3.87	.92	2.17	.56
4 ft.	1.01	.27	.38	.25	3.49	.98	2.15	.47
6 ft.	1.10	.25	.47	.22	4.85	1.25	3.11	.56
8 ft.	1.16				5.30			

(i) The jowar crop covered an area of  $\frac{1}{4}$  acre with 52 rows, each 110 ft. long, there being one plant per ft. in each row on the average. The mean height of the crop was about 6 ft.; (ii) The *suran* field was  $\frac{1}{2}$  acre in area with 37 rows of plants, each 110 ft. long, the distance between rows was 4 ft. and that between plants in the row 3 ft. The average height of the crop was 3 ft., the leaves spreading out at the top to a diameter of 2 ft. (iii) the sugarcane field was  $\frac{1}{4}$  acre in area and had 20 rows, each 110 ft. long, the rows being 3 ft. apart. There were 3 to 4 clumps of canes per foot. The plants had reached the flowering stage.

At the minimum temperature epoch, when the air layers are more or less stratified, the air flow is feeble and laminar. The increase of velocity with height is typical in the open. Inside the sugarcane, *jowar* and *suran* fields there is a decrease of wind velocity with height as the wind-break effect tends to increase with height owing to the foliage becoming denser. In *suran* which is only about 2 ft. high, the wind velocity begins to increase with height above the crop. The velocities at the minimum temperature epoch are generally between 0.2 to 1.2 m.p.h. and are often too feeble to be measured with the ordinary cup anemometer.

At the maximum temperature epoch there is a general increase in wind velocity. The difference in the wind-break effect of different crops is seen more clearly in the afternoon, the maximum effect being inside sugarcane, *jowar* coming next in order. The reduction of wind velocity above the *suran* crop (2 ft. high) persists even up to 6 ft. In the 'open' the wind velocity approaches 5.5 miles per hour at 8 ft.

The lowering of wind velocity by standing crops offers a certain degree of self-protection for the plants away from the borders of the field. The wind-breaking capacity of different crops within their respective heights may be seen in Table 16, where the mean wind velocity at different levels above ground inside different crops is expressed as a percentage of the wind velocity at corresponding levels in the 'open'. The data summarise the information obtained in a number of crops during the last few years and refer to afternoon conditions.

TABLE 16. MEAN WIND VELOCITY IN THE AFTERNOON IN DIFFERENT ENVIRONMENTS EXPRESSED AS PERCENTAGES OF THE VELOCITY AT CORRESPONDING HEIGHTS IN THE 'OPEN'

Height above ground	Percentage wind velocity						
	<i>Jowar</i>	<i>Suran</i>	Sugar-cane	Cotton	Wheat	Tobacco	Double beans
3'	29	52	18	32	20	51	30
6'	24	47	17	29	17	50	29
1 ft.	28	46	20	26	15	48	24
2 ft.	26	60	16	34	21	52	25
3 ft.	29	56	17	50	40	58	28
4 ft.	39	62	18	64	57	68	29
6 ft.	47	64	16	75	75	79	36
8 ft.	60	..	16	78	..	..	52

The ability to reduce air movements is in the order of sugarcane, wheat, *jowar*, double-beans, cotton, *suran* and tobacco. A more detailed discussion of this problem will be found in the paper by Raman (15).

*Air Movement inside an Oak Forest in Austria*

We may quote here the results of measurements made by Geiger in a thin oak forest with an undergrowth of beech. In a closed forest space even the large air masses which have fairly good freedom of motion between trunks remain very calm. In Fig. 36 the oak is drawn to scale. The three curves represent the change of wind velocity with height above the source of the forest during hours of strong wind. The curves represent measurements (a) in autumn 1928, (mean of 12 hours), (b) in spring 1928 (mean of 17 hours), when oak was in foliage and (c) in spring 1928 (mean of 28 hours) before the sprouting of the foliage. In all the three cases, the highest wind velocity occurs over the top of the trees while it is almost calm throughout between the trunks. This calm is most marked when the trees are in leaf but even the bare trunks, branches and twigs (Curve C) form a powerful obstruction to the wind.

Recently in India, the forest departments have begun to take some interest in the meteorological aspects of silviculture and it may be hoped that within a few years it may be possible to extend the scope of these investigations into forest environments.

Before concluding this section, it may be mentioned that gliders experience up-rising warm currents above a forest in the evening when nocturnal cooling has already commenced in the neighbouring 'open' spaces.

*The Variation with Environment of the Evaporating Power of the Air Layer near the Ground (2)*

As a climatic factor, evaporation has certain special features, as it takes into account directly or indirectly the effects of several meteorological factors like wind velocity, temperature and the saturation deficit of the air stream at any particular level on the loss of moisture by evaporation from a suitable measuring device. We have, of course, to dispense with instruments of large size and use the simple and handy 'Piche's evaporimeter'. This instrument occupies little space and several instruments may be exposed at different levels above ground to study the variation of the factor with height in different environments.

A number of calibrated Piche's evaporimeters were exposed in the open and inside selected crops at 1, 2 and 4 ft. above ground. The measurements of evaporation in 24 hours ending at 8 A.M. local time were recorded daily at Poona from December 1940 up to February 1941. The crops selected were jowar, double-beans, sugarcane and betel-vine.

Table 17 gives the mean values of evaporation in the different periods during the above season. The values of evaporation inside the crops have also been expressed as percentages of corresponding values in the open in the last 3 columns of the Table.

TABLE 17. EVAPORATION IN DIFFERENT ENVIRONMENTS (IN INCHES)

Environment	Evaporation in (inches) at the following heights			Evaporation as percentage of the open at corres- ponding level		
	4ft.	2ft.	1ft.	4ft.	2ft.	1ft.
5-12-40 to 10-12-40						
Open	.356	.387	.354	..	..	..
Rabi Jowar	.209	.163	.120	59	42	34
Double-bean	.132	.083	.068	37	21	19
Sugarcane	.117	.108	.098	33	28	28

TABLE 17. EVAPORATION IN DIFFERENT ENVIRONMENTS (IN INCHES)—*Contd.*

Environments	Evaporation in (inches) at the following heights			Evaporation as percentage of the open at corres- ponding level		
	4ft.	2ft.	1ft.	4ft.	2ft.	1ft
11-12-40 to 22-12-40						
Open .	·341	·366	·329	..	..	..
<i>Rabi Jowar</i>	·218	·157	·132	64	43	40
Double-bean	·160	·086	·083	47	24	25
Sugarcane	·108	·108	·098	32	29	30
23-12-40 to 6-1-41						
Open .	·354	·409	·375	..	..	..
Sugarcane	·123	·126	·101	35	31	27
Betel-vine	·098	·089	·074	28	22	20
10-1-41 to 31-1-41						
Open .	·369	·397	·384	..	..	..
Double-bean	·148	·117	·108	40	29	28
Sugarcane	·129	·120	·098	35	30	26
Betel-vine	·092	·083	·077	25	21	20
1-2-41 to 19-2-41						
Open .	·492	·556	·516	..	..	..
Double-bean	·215	·191	·148	44	34	28
Sugarcane	·166	·160	·132	34	29	26
Betel-vine	·120	·120	·101	24	22	20

In general, evaporation tends to increase with height. It is least in betel-vine where the wind velocity is least and the relative humidity maximum under the influence of irrigation coupled with the lack of ventilation (the betel-vine grows on some supporting structure to a height of 20 ft. and is irrigated at intervals of 10 days). Next comes sugarcane, also a dense crop, irrigated heavily at intervals and growing up to 12 ft. in height. In sugarcane, the wind velocity is slightly higher than in betel-vine. In double-beans and jowar the increase with height is more pronounced as the crops rise up to 5 or 6 ft. only above ground. Table 18 gives the mean values of evaporation expressed as percentage of that in the open at the corresponding levels. For reference, the actual values of evaporation in inches at different levels in the open are also given at the bottom of the table.

TABLE 18

Environments	Evaporation as percentage of the open at corresponding level		
	4 ft.	2 ft.	1 ft.
<i>Rabi Jowar</i>	62	43	37
Double-bean	41	27	25
Sugarcane	34	30	27
Betel-vine	25	21	20
Actual evaporation in the 'open' in inches	0.382	0.423	0.292

A more detailed discussion of these measurements\* in relation to temperature, humidity and wind velocity will be taken up when further data are collected.

#### *Importance of Micro-climatic Observations*

In concluding this brief summary of some of the interesting features of micro-climatology of crops, it is to be specially emphasised that the climates of crops define their actual environment and the conditions under which crops, their pests or their diseases develop. The crop's climate is not a simple function of the standard micro-climate of a locality and as such has to be actually recorded if it is to be known precisely. Besides their use in establishing exact crop-weather relationships, micro-climatic observations also help to define the meteorological conditions most favourable for the application of sprays and fumes which can help to suppress plant diseases, and pests (a kind of chemical warfare against these enemies of the crop). It will be obvious too that by varying the plant density one can bring about partial control of the micro-climate.

#### MOISTURE BALANCE AT THE GROUND SURFACE: FACTORS CONTROLLING FATE OF RAINFALL

There are various factors which control (119) the water or moisture balance at the surface of the earth. The precipitation received as rain (and or snow in the higher latitudes) is disposed of as follows :

- (a) Evaporation from the soil
- (b) Transpiration from plants
- (c) Surface drainage
- (d) Percolation into the soil
- (e) Retention by the soil layers and
- (f) Underground drainage.

The factors (c) and (f) contribute to the run-off into the river systems. If the moisture balance sheet refers to the year as a whole and for a big area like the catchment of a river (67), the Hydrologist often states the position roughly, (on the assumption that the mean moisture content of the soil layers themselves does not vary sensibly from year to year), as follows:

Precipitation = Run-off + Evaporation and transpiration.

\*Mr. P. K. Raman recorded these data.

The investigation of these problems and the development of the necessary experimental techniques for estimating the various factors entering into the moisture balance have assumed great urgency now that 'Food Production' and 'Multipurpose Projects' have assumed the highest priority.

### *Evaporation and the Water Balance*

To the physicist, evaporation from a liquid surface is a function of the vertical gradient of the partial pressure of the vapour above the liquid surface and of the molecular diffusion constant. When we deal with a water surface fully exposed to the atmosphere, experience shows that the loss by evaporation from such an exposed surface is for all practical purposes a function of the velocity and the saturation deficit of the air flowing over the water surface. When the area of the water surface is relatively small as in the usual type of pan evaporimeter (e.g., the U. S. A. Standard Evaporimeter with its water surface 1 foot above the ground and 4 feet in diameter) the rate of evaporation is exaggerated by the border effect as every parcel of air picks off moisture before it comes fully under the influence of the water surface. This may be contrasted with what happens when the centre of a lake or large expanse of water is affected by the flow of air which has already been enriched with moisture picked up by it while traversing the marginal portions of the extended surface. We may, therefore, designate the evaporation measured with a vessel of relatively small dimension, as in the pan evaporimeter referred to above, as representing the 'Evaporating Power' of the air layers near the ground. As contrasted to this we have the 'Natural Evaporation' from a big lake or an extensive land area, which, other conditions remaining the same, will be significantly less than the 'Evaporating Power'. We may remember all the time that in both cases the controlling meteorological factors are the same, *viz.*, wind and its saturation deficit.

It may also be recalled that the nature of the relation between the 'Evaporating power' of the wind and the controlling meteorological factors can be represented by an equation such as the one below which we owe to Rohwer (141) :

$$E = (1.465 - 0.0186 B) (0.44 + 0.118 W) (e_s - e_d)$$

where E is the mean daily evaporation in inches.

W is the mean daily wind velocity in miles per hour at the level of the evaporating surface,

$e_s$  is the vapour pressure in inches of mercury at the mean daily value of the temperature of the water surface,

$e_d$  is the mean daily value of the vapour pressure in inches of mercury of the air flowing over the evaporating water surface (equal to the saturation vapour pressure at the dew point),

and B is the mean daily value of the barometric pressure in inches of mercury.

Rohwer's formula has been slightly modified and used for computing the 'Evaporating Power' at a network of stations in India for drawing provisional charts of this factor. In this modified formula, the last term has been replaced by  $(100/h - 1)e$  as we have charts have been discussed by Raman and Satakopan working under the present writer no records of the water surface temperature ; h is the relative humidity of the air. The in 1934 (2).

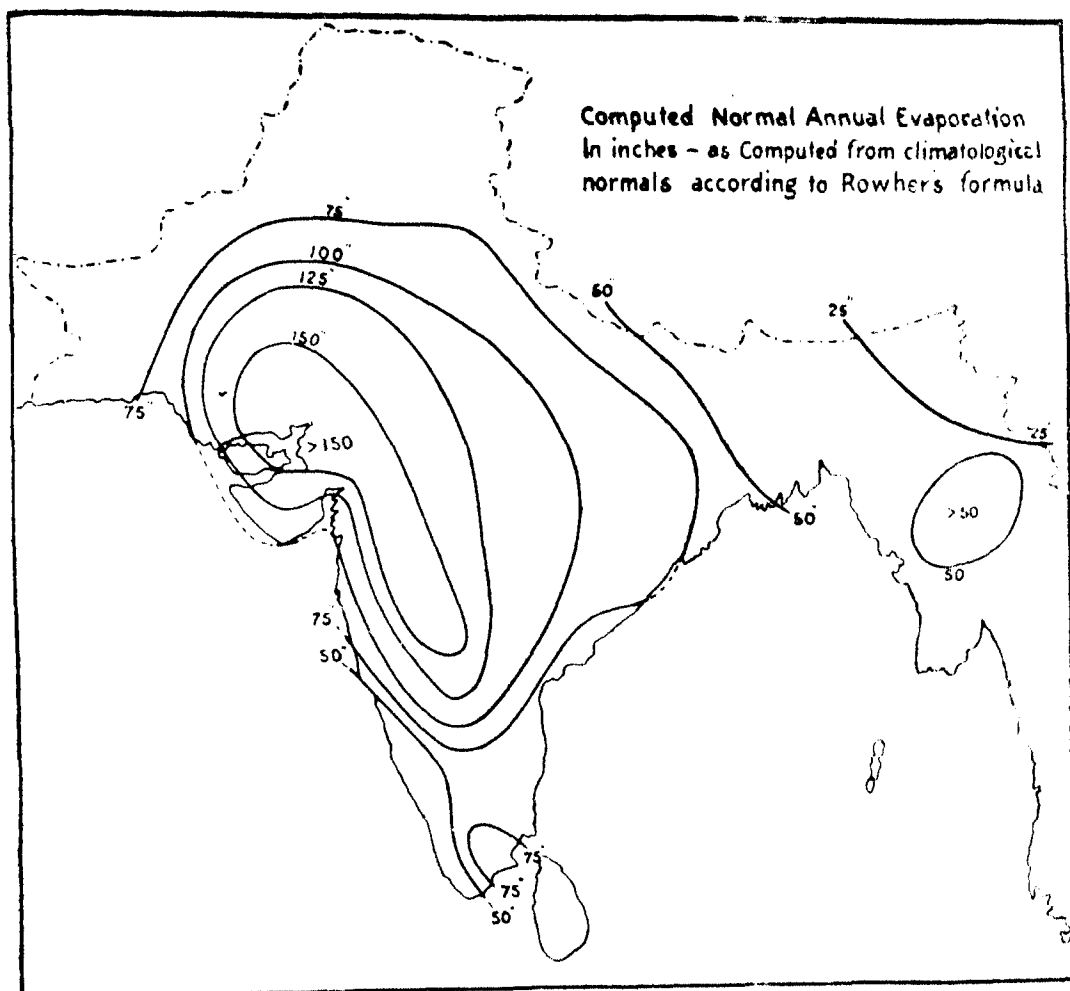


FIG. 38. Computed normal annual evaporation (inches)

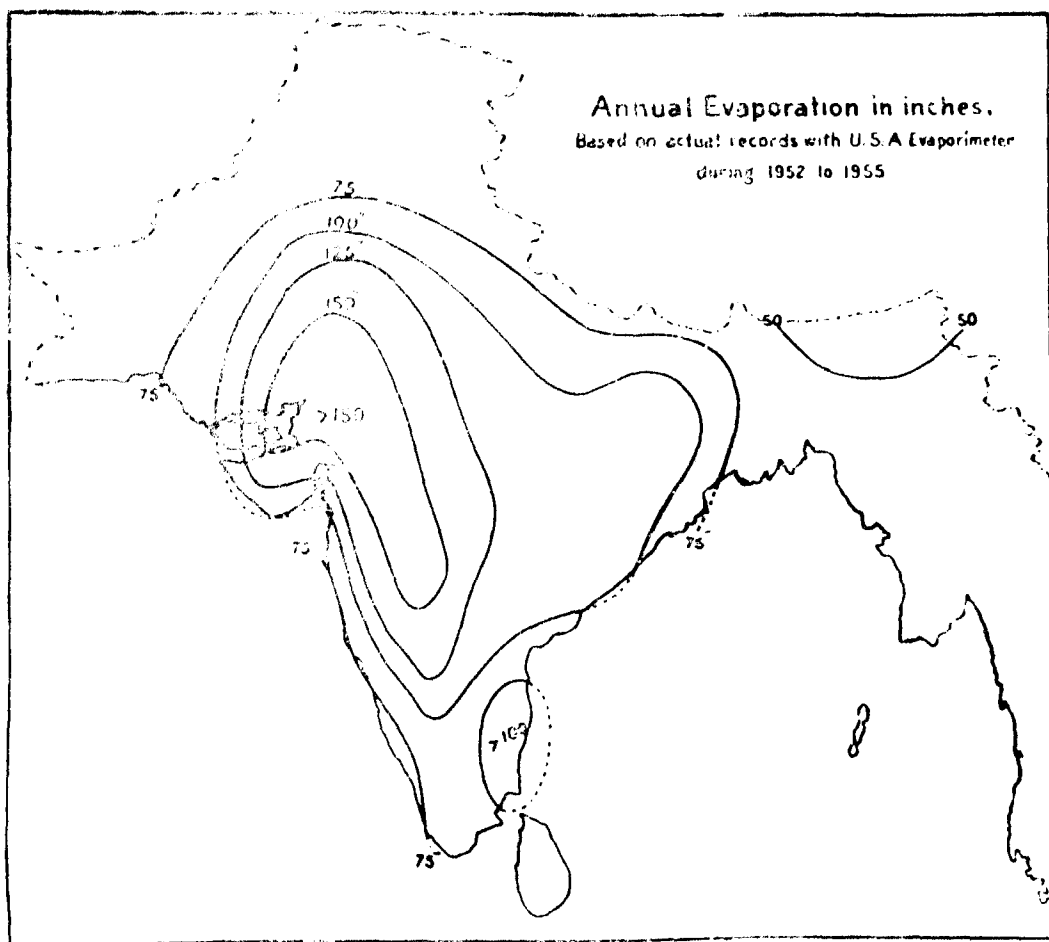


FIG. 39. Annual evaporation in inches (1952-55)

The hydrologist is concerned with the 'Natural Evaporation' from large reservoir and lakes, while the agronomist has to reckon with the loss of water by direct evaporation from exposed patches of the soil in combination with the transpiration from the growing crops (called 'Evapo-Transpiration'). The natural evaporation or evapo-transpiration from such extensive areas of water or land respectively also depends on the wind velocity and saturation deficit but in the absence of border effects the water losses are significantly less than what is indicated by a pan evaporimeter which records the 'evaporating power' of the air.

It is impossible to measure directly by the usual gravimetric or levelling methods the 'Natural Evaporation' from an extensive area. Attempts have been made by a number of workers to estimate natural evaporation by what is known as the 'Energy Balance Method' as well as the 'Turbulent Diffusion Method'. The question, however, arises if one may estimate 'Natural Evaporation' from the values of 'Evaporating Power' recorded with the U.S.A. Standard Evaporimeter. This last possibility has also been explored by the present writer and his collaborators during the last few years. The method and its scope will be discussed in the following paragraphs.

Before taking up this topic it may be mentioned that the evaporation data computed by Raman and Satakopan for India, month by month (see Fig. 37) clearly show that the semi-arid tract to the east of the western ghats, consisting of the Bombay Deccan and the adjoining parts of the central parts of India represent the area of maximum evaporating power of the air layers near the ground, during the dry season November to May. When the monsoon sets in June the area of high evaporating power shifts rapidly to North-West India where the monsoon is the latest to set in and is brief in its duration. With the retreat of the monsoon by October, the area of high evaporating power shifts back to the Bombay Deccan and its neighbourhood and remains there until the next monsoon. The spatial variation of the mean annual evaporating power shown in Fig. 38 further emphasises this most important feature, *viz.*, that the area of maximum evaporating power is the Bombay Deccan and its neighbourhood. The subsidiary maximum over the South-East of the Peninsula is less conspicuous. These features are confirmed more or less by the actual records of U. S. A. Standard Evaporimeters set up recently at a network of stations in India (see Fig. 39).

*How to Estimate 'Natural Evaporation' or 'Potential Evapo-Transpiration' from an extensive wet area (lake or land saturated with moisture) from the evaporating power as recorded from a U.S.A. Standard type of evaporimeter.*

The U. S. A. Standard Evaporimeter is usually exposed on a wooden platform with its water surface 1 foot above the ground so as to ensure the continuity of records during wet weather. It is important to note that the evaporation from such a water surface will be affected by the increased wind velocity at 1 foot as compared to that at the ground surface.

To arrive at a conversion factor to reduce evaporation from the standard instrument under normal exposure to that from a similar water surface kept flush with the ground, a second instrument of the same type was installed at the Central Agricultural Meteorological Observatory at Poona and comparative observations recorded during a few years. If  $E$  is the evaporation from the instrument normally exposed with the water surface 1 foot above the ground and  $E_0$  the evaporation from an exactly similar surface kept flush with the ground, then from this series of comparative observations it is found that

$$E_0 = 0.845 E.$$

The conversion factor 0.845 is the average value obtained during the dry season during a number of years.

The value of  $E_o$  represents the evaporation from an isolated water surface 4 feet in diameter, kept flush with the general level of the surrounding bare ground. This value will be equal to the 'Natural Evaporation' from an extensive area only when the area surrounding the water surface is also completely wet or saturated with water. This will be the case only during rainy weather or when the surrounding area is heavily irrigated with water. Under such conditions the above equation itself will give 'natural evaporation' from an extensive wet land area.

When, however, the surrounding land is dry, the values of  $E_o$  will need a further reduction. This further reduction factor is arrived at by the following experiments conducted at Poona. A number of similar evaporimeters was installed with the water surfaces flush with the ground. They were surrounded each with a ring of wet soil, the width  $R$  of the wet ring varying from 4 ft. to 20 ft. respectively. One instrument was kept without any wetting. The comparative observations recorded with this set of instruments showed clearly that the ratio  $E^{or}/E_o$  of the evaporation is 1.0 when  $R$  is zero but decreases rapidly with increase of  $R$ , attaining a limiting value of the order of 0.70 when  $R$  has a large value. Using this value as the conversion factor, we have.

$$E^{or} \propto 0.70 \times 0.845 \times E = \text{approximately } 0.60 E$$

Thus, during clear weather when the ground surrounding the evaporimeter is dry,  $E^{or} \propto$  the natural evaporation from an extensive wet ground or a lake may be estimated from the observed value of  $E$  by multiplying by the above multiplying factor 0.60. When the surrounding area is already wet with rain or irrigation,  $E_o$  itself as estimated under such conditions becomes equal to  $E^{or}$ .

By using the simple relations given by the above equations, we may estimate approximately the evaporation from extensive areas of wet soil saturated with water. This estimate of evaporation in a given month for any particular station will be obtained by using the factor 0.845 for rainy days and 0.60 for dry days. The quantity so estimated is not likely to differ significantly or largely from the loss of moisture by evaporation and transpiration combined from a similar area covered with vegetation. This is suggested by recent preliminary experiments conducted at Poona from bare soils in pots saturated with water and similar soils with growing plants. We may, therefore, provisionally call the natural evaporation from ground saturated with water as approximating to "Potential Evapo-Transpiration" to use the recent terminology of Thornthwaite.

Values of  $E^{or} \propto$  representing what the evaporation is likely to be from an extensive lake or from an extensive area of wet or water logged land or from a cropped area at full irrigation have been computed, using provisionally the computed normal values of Raman and Satakopan. The annual values of Potential Evapo-Transpiration (P.E.T.) so obtained are shown in Fig. 40 and these are naturally much lower than the evaporation values of Fig. 38; but the general pattern of "P.E.T." preserves, as it to be expected from the climatological pattern, the same general features, *viz.*, a centre of high potential Evapo-Transpiration therefrom; the secondary high potential over south-east Madras is also brought out.

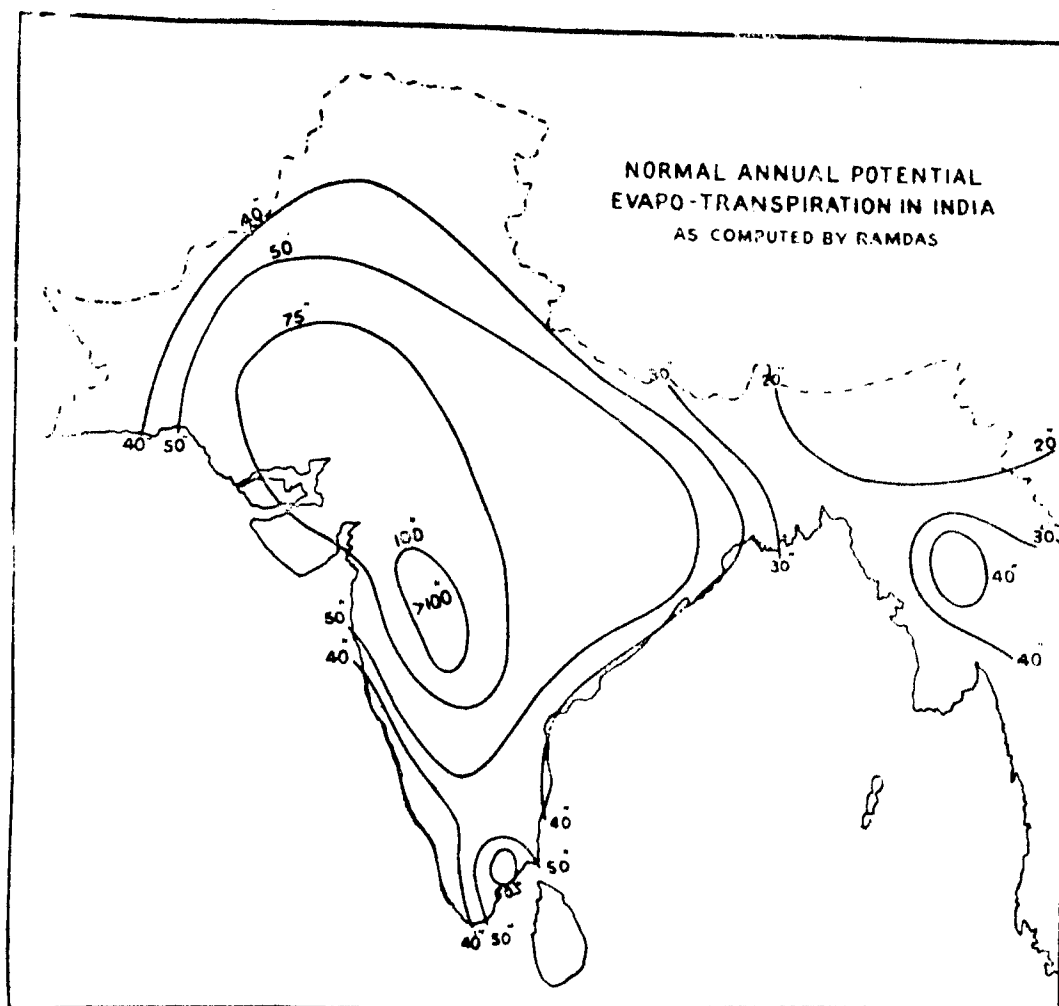


FIG. 40. Normal annual potential evapo - transpiration

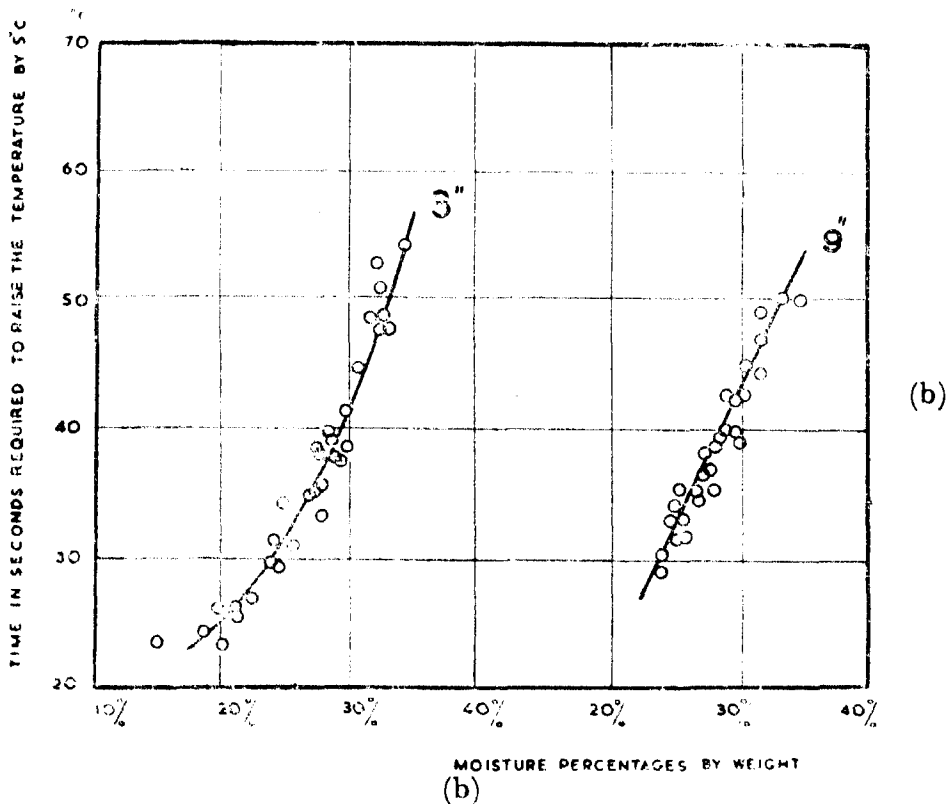
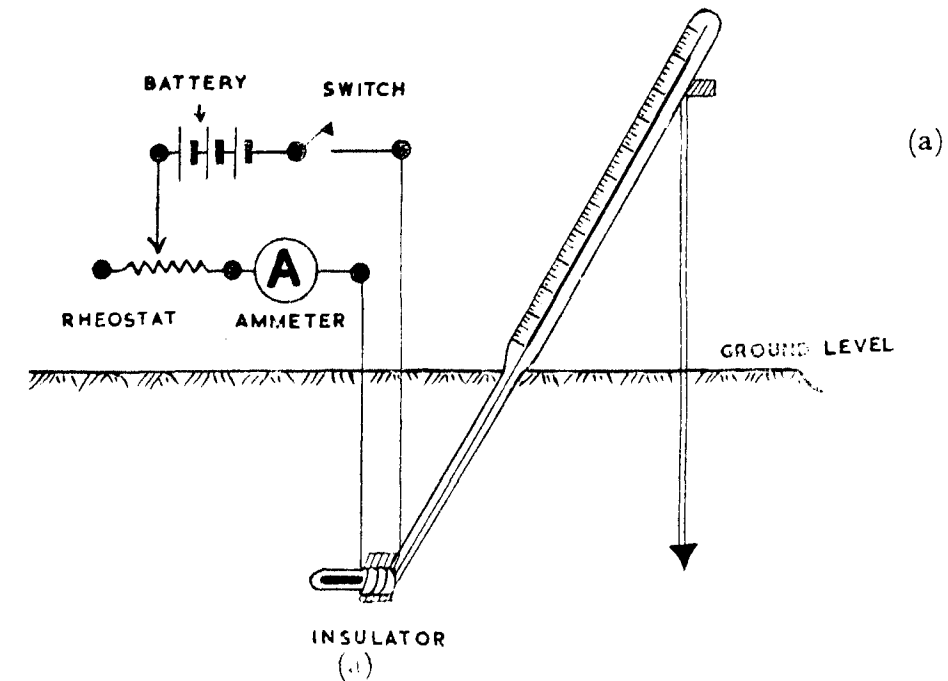


FIG. 41. Diagram showing (a) the methods of installation and (b) the calibration of the new soil moisture instrument

Actual "P.E.T.", is soon likely to be recorded at a network of stations all over the world, but meanwhile, rough estimates of the order of magnitude of this phenomenon which is of vital concern in Food Production\* may be attempted by the above method from simple measurements of evaporation from small pans like the USA type. Conversion factors like those referred to earlier are all that is necessary for this approach to the problem.

*Effect of depth of free water table or zone of saturation in the Sub-soil on the Rate of Evaporation from the top of the Soil Surface.*

The present writer has summarised the soil moisture and evaporation investigations in progress at the Central Agricultural Meteorological Observatory at Poona in a recent paper (63). Evaporation from a soil surface is comparable to that from a free water surface only so long as the soil surface remains saturated with water. When the soil surface dries up, the evaporation will depend also on the upward or capillary ascent from the wetter soil below. When this supply too diminishes, the soil surface will ultimately begin to exchange water vapour with the air layers above yielding some of its hygroscopic moisture to the air during the day until the maximum temperature epoch and re-absorbing water vapour from the air layers during the rest of the day and night.

The experiments conducted at the Central Agricultural Meteorological Observatory on the dependence of evaporation  $E_z$  on the distance  $z$  between the soil surface and the free water-table (using a series of soil evaporimeters) led to the simple relation (64).

$$\frac{E_z}{E_0} = 10^{-\alpha z}$$

where  $E_0$  is the evaporation when  $z = 0$  (equivalent to that from a free water surface) and  $\alpha$  is a constant, characteristic of the particular soil. Thus, if we know the value of  $E_0$  or  $\alpha$  when an extensive area of bare soil is saturated with water and wish to estimate  $E_z$  in a similar area where the water table or zone of saturation is  $z$  cm below the surface (easy to ascertain by digging an experimental pit) this may be computed from the above exponential relation.

In the above paragraphs simple experimental techniques of estimating evapo-transpiration from saturated soils or cropped land under full irrigation have been suggested. Methods of estimating evapo-transpiration  $E. T.$  from cropped land with unsaturated surface soil and with the zone of saturation some distance below need investigation.

The evaporation loss decreases rapidly with the increase of  $z$ , so that if sub-soil irrigation is resorted to at a depth below 2 ft., only a small fraction of the water is lost by evaporation.

The movements of moisture through the soil depend on the pore space and permeability of the soil. The present writer and his co-workers at Poona (49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 61, 62), have investigated the influence of some salts like sodium carbonate, lithium carbonate etc., on the swelling of the colloidal fraction of the soil and of other salts like sodium chloride, calcium chloride, etc., on the shrinking of the swollen particles. These phenomena, *viz.*, swelling and shrinking are of very great importance in controlling the permeability of the soil layers to moisture (*e.g.*, in capillary ascent, soil drainage etc.).

\*Experiments are in progress in a number of countries including India to test the efficacy of evaporation control by covering the free water surface of a lake or reservoir with a mono-molecular film of Cetyl Alcohol. This technique claims to reduce evaporation losses by about 30 to 40 per cent. under favourable conditions.

The movements of moisture through the soil and its variations at any point in the soil are usually studied by the old method of sampling with the soil auger and estimating the moisture loss in a steam oven. All this often takes up to a week. Momin (59), working in our laboratories, has devised a new instrument which, once it is calibrated, enables one to read off the soil moisture per cent almost instantaneously. This instrument consists of a soil thermometer, the bulb of which is heated by passing a fixed electrical current through a coil of wire wound round it. The electrical current from a 6-volt battery passes through a rheostat and is adjusted so as to show a current of 0.3 amperes on an ammeter in the circuit. The time taken by the soil thermometer installed in the soil to rise by  $5^{\circ}\text{C}$  is noted with a stop watch.

This time is short, of the order of 20 seconds, for dry soil. When the soil is saturated with moisture the heat generated at the bulb is conducted away at a faster rate by the surrounding soil and it takes up to a minute for the  $50$  rise to be recorded. Fig. 41 shows a schematic diagram of the instrument and the calibration curves for two instruments installed at the Central Agricultural Meteorological Observatory. Momin has recently designed a portable type of this soil moisture instrument.

Fig. 28 shows the seasonal variation of moisture per cent at different depths in the soil; the rainfall in inches is shown in the upper portion of the figure. These data described in an earlier section obtained by the soil auger sampling method show the variations of soil moisture characteristic of the different seasons at Poona. These estimates will be easier now by the new method described in the previous para.

#### NEW INSTRUMENTS AND EXPERIMENTAL TECHNIQUES

For a description of the simple standard instruments used for recording the routine observations needed from a network of observatories for synoptic meteorology (weather forecasting) e.g., atmospheric pressure, air temperature and humidity, wind direction and velocity, rainfall, clouds, visibility, etc., a reference may be made to the "Instructions to Observers" and the technical circulars of the India Meteorological Department. These data are representative of the general or macro-climate of a locality, care being taken to get well away from the disturbing effects of the air layers nearest to the ground.

In agricultural meteorology, however, we are specially concerned with the air and soil layers nearest to the ground in which plants have their being. We wish to investigate the interaction between the plant and its environmental factors and this field of investigation is rich in opportunities for the experimental physicist as well as the biologist.

At Poona the experimental researches in agricultural meteorology are being conducted at the Central Agricultural Meteorological Observatory (see Frontispiece). Some of the special instruments and techniques [4, 106(a), 107], evolved may briefly be described here.

#### *Sensitive Portable Galvanometer and Thermo-couple Set*

A sensitive portable galvanometer and thermo-couple [107 (1937-38)] set for measuring the temperatures of plants growing under field conditions has been a long felt want of agriculturists and plant physiologists. A sensitive and at the same time robust and portable type of galvanometer was evolved by the Laboratory Apparatus Works, Poona, at the instance of and specifications from the Agricultural Meteorology Section. The galvanometer connected to the copper-constant thermal junctions is shown in Fig. 42. One of the thermo-

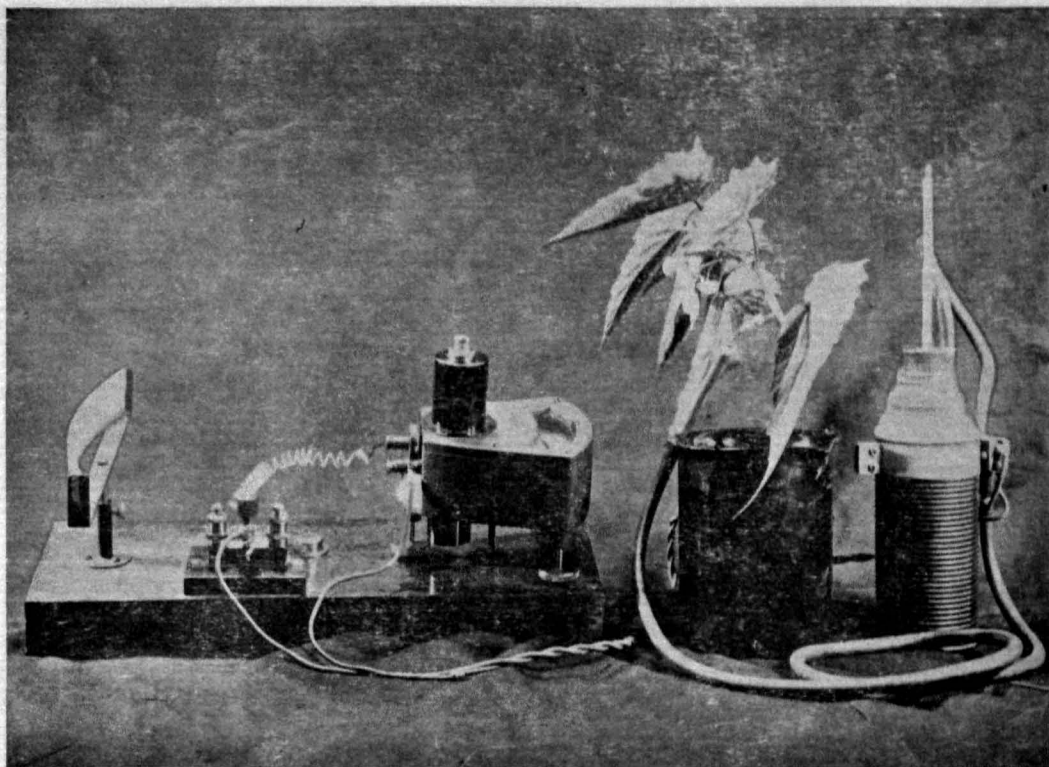


FIG. 42. Portable galvanometer and thermo-couple set for the measurement of plant temperature

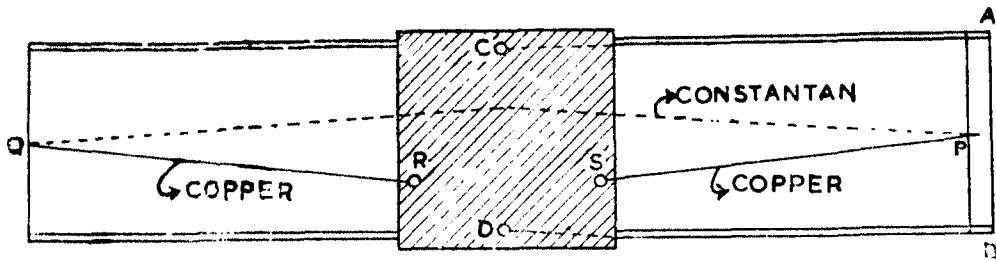


FIG. 43. Apparatus for the measurement of heat loss by convection

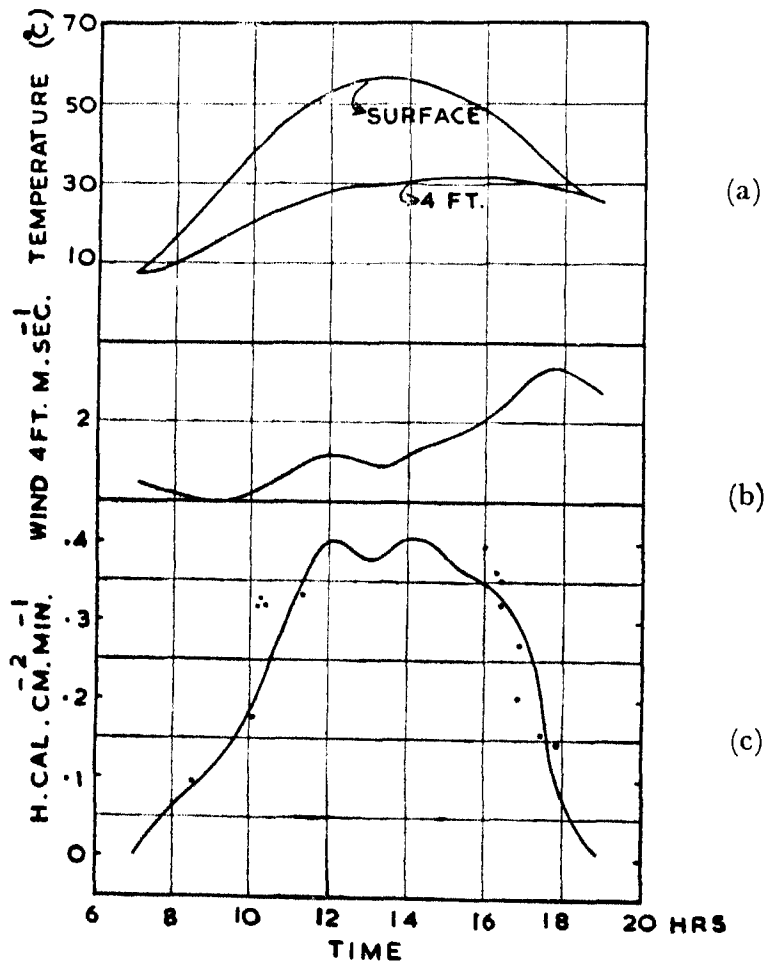


FIG. 44. Hourly variation of (a) heat loss by convection, (b) wind velocity at 4 ft. and (c) air temperature at surface and 4 ft.

couples is kept immersed in water at a constant temperature inside the thermos flask and the other junction is inserted into the plant. The galvanometer deflections may be read off with the simple mirror and scale device provided. While in use in the field, the instrument is screwed on to a metal tripod and the levelling is adjusted with a circular spirit level fixed to the galvanometer. After use, or while moving from place to place, the galvanometer can be clamped by means of a convenient device without prejudice to its zero reading on being released again. The galvanometer readings are converted into the corresponding temperature values with reference to a calibration curve.

#### *Temperature Alarm Apparatus [167 (1937-38)]*

This consists of a bimetallic spiral of brass and invar, actuating a contact maker which closes an electric circuit through an alarm bell and a dry battery as soon as the temperature of the spiral has fallen to a previously adjusted temperature. The instrument may be installed in a suitable place in the field and the connections made in such a way that an alarm bell kept in the farm house will ring as soon as the air temperature has fallen below a value indicating that frosty conditions are likely to set in soon after. This gives some time to the farmer to take such precautionary measures as may be possible, such as starting suitable heaters or country fires for warming up the orchard. Arrangements have been made to have the instrument manufactured at Poona at a price which would be within the means of the ordinary orchard keeper, e.g., the owners of vine gardens at Nasik.

#### *Instrument for the Measurement of Heat Loss by Convection*

It is possible to obtain records of the total energy received from the sun and the sky by unit area of a horizontal surface at ground level with the help of a recording solarigraph, but to account for the heat balance at the surface of the ground we have also to obtain the following estimates :

1. the heat exchange by conduction between the soil surface and the soil layers below,
2. the heat loss by convection above the ground,
3. the heat exchange by radiation processes between the surface and the atmosphere, and
4. the heat loss and gain by evaporation and condensation respectively.

Items (1), (3) and (4) can be estimated by direct methods. Item (2), *viz.*, the heat removed from the heated ground by the convecting air layers above it, is usually estimated indirectly. The simple instrument which has been designed at Poona (12) to measure directly the heat transferred from the ground by convection is shown in Fig. 43. A thin polished silver-plated constantan strip AB is mounted between the ends of a pair of parallel copper rods (nickel-plated and polished) carried on a base of ebonite. The copper rods are connected to two terminals C and D. One junction P of a copper-constantan thermo-couple is placed in thermal contact with the centre of the strip AB; the other junction Q is suitably mounted on silk fibres so that it can be placed in contact with the surface of the ground. The underside of the constantan strip is lined with a layer of cork so that, when placed on the ground, it is thermally insulated from it. R and S are terminals for connecting the thermo-couple to a suspended coil galvanometer. The strip AB is heated electrically as required and the current measured on a calibrated ammeter. The convection

apparatus is exposed in the open, while the battery, electrical instruments, etc. are housed in an adjoining hut.

The measurement of the heat loss is made by adjusting the current through AB so as to equalise the temperatures P and Q. This is indicated by zero deflection in the galvanometer. Knowing the electrical resistance and area of AB and the co-efficients of absorption and emission of radiation by the strip in the visible and infra-red regions of the spectrum, it is possible to calculate the heat lost by convection. Fig. 44 shows the hourly variation of the heat loss by convection expressed in gram calories per square centimetre, per minute as well as the corresponding values of wind velocity and air temperatures on a clear day in February. The total loss during the day comes to 175 calories. The integrated heat loss varies from 175 in February to 340 calories per day in May.

*Portable Percolation Gauge* [42, 107 (1934)].

A Portable Percolation Gauge having the same diameter as the standard Symon's Rain-Gauge has been designed (Fig. 45). The instrument consists of a cylindrical vessel of the required height and 5" in diameter to contain the soil and a funnel which drains water percolating through the soil into a suitable receiver below. The soil rests on a perforated disc at the bottom of the cylindrical vessel. The cylindrical container is provided with a protecting collar outside to prevent external spray from finding its way into the receiver during rains when the instrument is exposed outside. A series of these gauges containing soil 6", 1', 1½', 2', etc., in depth can be exposed in the open to measure the fractions of rain water retained by and percolating through the soil columns. These gauges are also used in the laboratory to measure the water-holding capacity of different soil samples.

#### *Evaporation from Free Water Surfaces*

Evaporation from a free water surface is measured with different types of instruments [106(a)]. The U.S.A. Standard Evaporimeter (Fig. 46) with a reservoir 4 feet in diameter and a hook-gauge (in stilling well) and the Athavle Open Pan Evaporimeter (Fig. 47) 1 foot in diameter and with a micrometer gauge have been found to be most convenient for measurements in the open. The U.S.A. evaporimeter is suitable for use at important centres whereas the latter is convenient for use at the ordinary experimental farms. For the study of evaporation at various levels above ground and in different environments the simple Piche Evaporimeter has been found to be the most convenient type.

#### *The Soil Evaporimeter (47)*

The estimation of the loss of moisture from the soil surface by evaporation is of great importance in agricultural meteorology, hydrology, etc. A simple instrument has been designed at Poona, with the help of which the loss of water by evaporation from a soil surface with the water table at various depths below the soil surface can be measured. Fig. 48 gives a sketch of this instrument. The soil evaporimeter consists of a cylinder 5" in diameter with a perforated bottom which rests in contact with water in a closed reservoir. The cylinder is filled with soil and the reservoir is filled with water through an opening on one side at the top of the reservoir. The level of the water in the reservoir can be observed in the vertical glass tube attached to a side tube. Evaporation from the soil is determined by weighing the evaporimeter at intervals of time, the difference in weights giving the loss of water by evaporation during the interval.

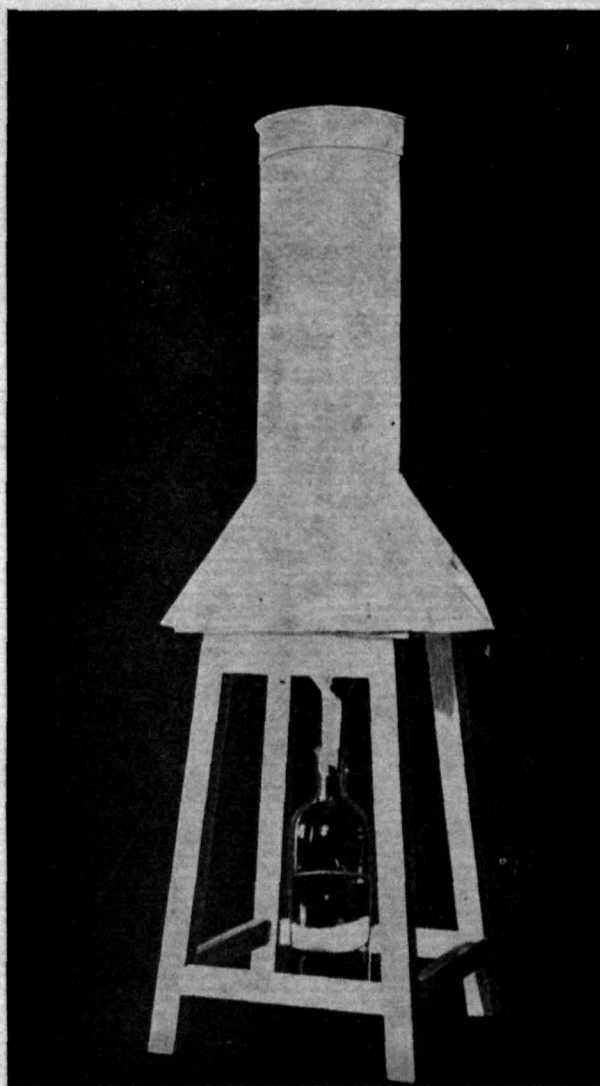


FIG. 45. The portable percolation gauge

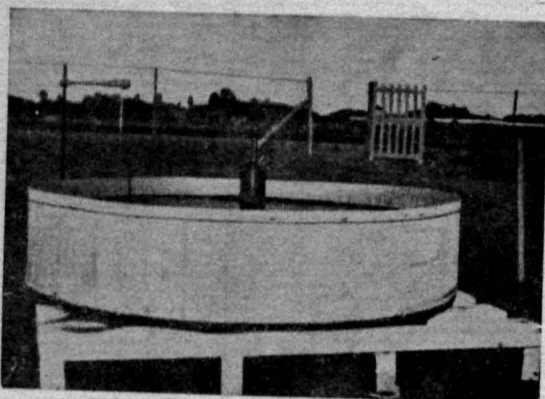


FIG. 46. The U. S. A. standard evaporimeter

FIG. 47. The Athavle open pan evaporimeter

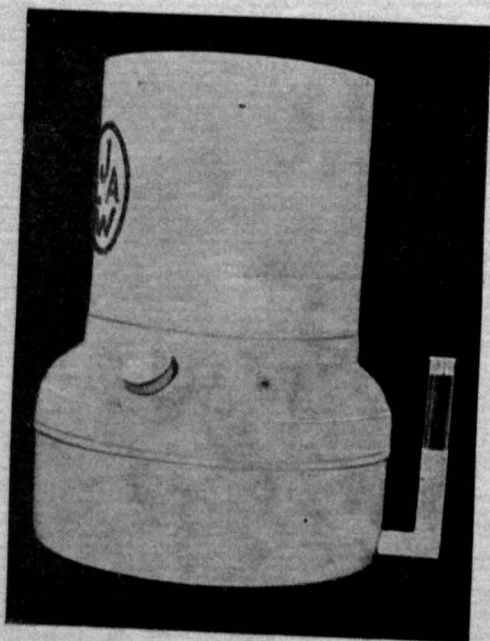
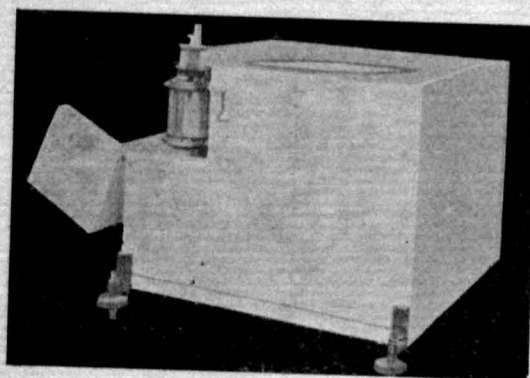


FIG. 48. The soil evaporimeter

From observations at Poona with a series of soil evaporimeters with the depth of the free water surface or the wet zone ranging from 6" to 3' it is found that for any soil,  $E_z$ , the evaporation when the wet zone is  $z$  cm. below the soil surface, can be expressed as

$$\frac{E_z}{E_o} = 10^{-\alpha z}$$

Here,  $E_o$  is a constant representing the evaporation when the wet zone is up to the soil surface itself and  $\alpha$  is another constant. The use of this technique for estimating natural evaporation losses from unsaturated field has already been referred to.

#### *The Improved Soil Evaporimeter (4,63)*

(This type is also used for studying root and shoot development of plants in relation to the distance between the soil surface and the water table below.)

In arid tracts, it is advisable to resort to sub-soil irrigation in order to minimise the loss of water by evaporation directly from the soil surface. If arranged suitably, sub-soil irrigation would enable plants to make the most efficient use of the scanty water that may be available in such tracts. The interesting questions that arise are: (1) the depth to which plant roots can penetrate in search of water and (2) the relation between the plant root and shoot development and the depth of the free water table. The study of these problems has been undertaken at the Central Agricultural Meteorological Observatory at Poona with the help of the specially designed soil evaporimeter described below.

Fig. 49 shows a sketch of this apparatus which is a modification of the soil evaporimeter described in the earlier section. It consists of a metallic drum ABCD, which is 12" in diameter and 37" high. To the lower end of this drum is fixed a small side tube to which is attached a glass tube LM. This enables the level of water inside the drum to be read at any time. The drum is provided with a ring 1" high at the bottom; inside this ring is inserted the inner cylinder EFGH which is 6" in diameter and 38" high. The inner cylinder has a detachable perforated metal disc 1" above its lower notched end. The soil inside the cylinder is supported on the perforated disc which keeps the soil in contact with the water in the drum through the notches near the base of the cylinder. The drum is closed at the top by a lid having a hole in the centre through which the inner cylinder comes out. The lid is also provided with a small hole with a screw cap through which water can be poured into the drum.

To study how the root and shoot development depend on the distance between the water table and the soil surface a number of instruments of the above type were used. 37" layers of black cotton soil of Poona were packed in the central cylinder for growing plants. Nine pairs of 5-day old seedlings of jowar were transplanted into the vessels. The level of the free water tables in the drums were adjusted in pairs of instruments at 1", 7", 13", 15", 17" and 19" respectively below the soil surface. After three weeks the plants were removed and the roots and shoots measured. Fig. 50 shows graphically the results of one such experiment. It will be seen that when the free water table is very near the soil surface the root development is restricted and as the water table recedes from the soil surface the root development is seen to increase, showing that roots tend to reach the water table. This increase terminates abruptly when the water table is lowered beyond 17" below the soil surface, as the seedlings are unable to survive under these circumstances.

The shoot length shows a comparatively smaller dependence on the water table. It may be remarked that there is a considerable variation in the depth of the colour of the green foliage, the plants growing in pots where the water table is very near the surface being much lighter in colour than those where the water table is further away from the soil surface.

*Apparatus to measure the Effective Rainfall or Irrigation [107 (1940-41)]*

A simple instrument has been designed to study the fate of rain or irrigation water arriving at the surface of the soil. This instrument (Fig. 51) consists of a brass cylinder MN, open at the top and closed at the bottom. This is sunk in the ground so as to have its top flush with the ground surface and with its sides and bottom well in contact with the soil. Inside this, there are two other brass cylinders CD and KL the lower and upper ends of which can be fixed to each other by means of bayonet joint. To the lower end of the upper cylinder CD is soldered a funnel G leading into a receiver H placed in the lower cylinder. The whole arrangement is such that no water can enter the instrument except through the soil column which is packed into the upper cylinder CD. Water received at the surface of the soil column in the instrument partly evaporates and is partly held by the soil itself, the surplus percolating into the receiver H in the lower cylinder. All of these values can be measured with the help of this instrument by a series of weighings. This instrument when designed in its final form, after the present trials, may be expected to provide a simple and direct method of estimating what fraction of the water supplied to the soil surface, whether as rainfall or by irrigation, is lost by evaporation and by percolation through different depths of the soil and what fraction is actually retained by the soil layer under consideration.

*Electronic A. C. Bridge for the Measurement of Electrical Conductivity of Soils, Plant Stem or Sap and Solutions*

The A. C. bridge first used by Kohlrausch for the measurement of electrical conductivity of solutions has found many applications as a measuring instrument in soil physics. But the limited sensitivity and accuracy of the instrument when used for measuring very high or very low resistances has prevented its use in some problems of soil physics.

An A. C. bridge has been developed in the Agricultural Meteorology Section at Poona (58) which, by making use of thermionic tubes for amplification and an electron ray tube for the visual indication of the conditions of balance in the bridge, makes it possible to measure electrical resistance ranging from a fraction of an Ohm to several million Ohms with an error of less than 0.2 per cent. Fig. 52 gives a schematic circuit diagram of this apparatus. The conventional buzzer used in Kohlrausch's method for generating the alternating e.m.f. for the bridge has been replaced by an audio frequency oscillator which can generate sinusoidal e.m.f.'s with frequencies ranging from 5 to 60,000 cycles per second. The use of the electron-ray tube as a null point indicator has eliminated all the restrictions which are imposed when a telephone is used for detecting the conditions of balance, *i.e.*,

1. Frequencies outside the audible range can be used. The use of high frequency e.m.f.'s is essential for measuring the conductivity of strong electrolytes, etc., where pronounced polarisation effects are produced if low frequencies are used.
2. Errors due to the logarithmic response of the human ear are eliminated.
3. The telephone is a non-phase selective detector.

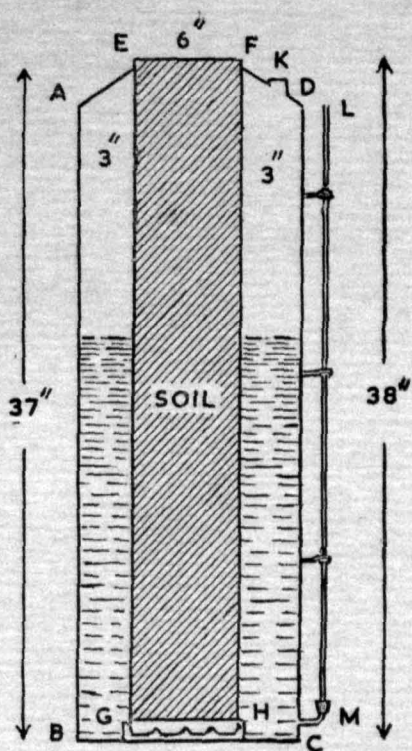


FIG. 49. The new or improved soil evaporimeter

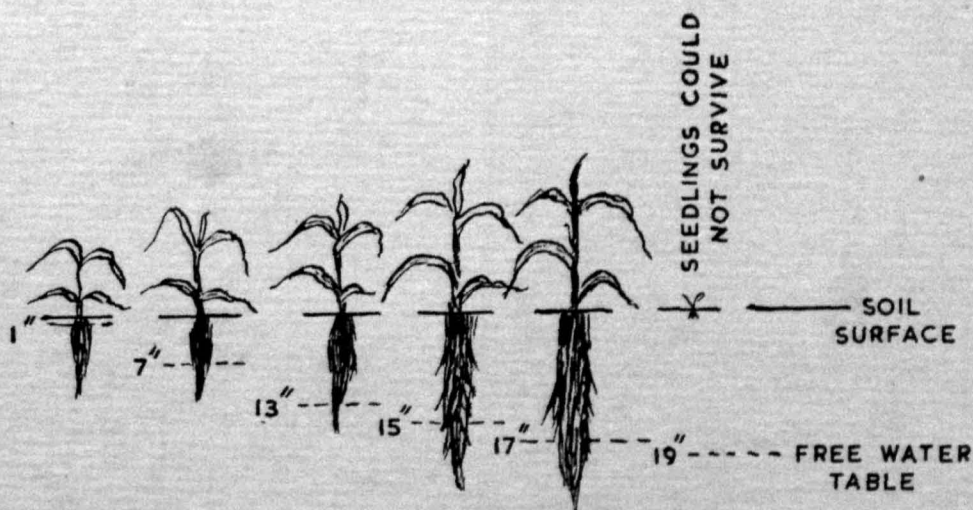


FIG. 50. Schematic diagram showing the dependence of root and shoot development of jowar seedling on the distance between the soil surface and free water table

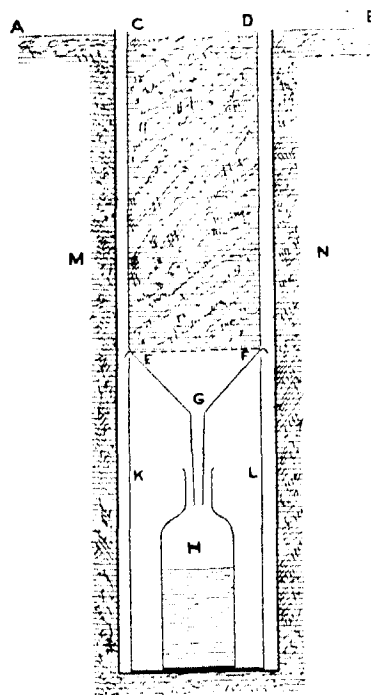


FIG. 51. The effective rainfall instrument

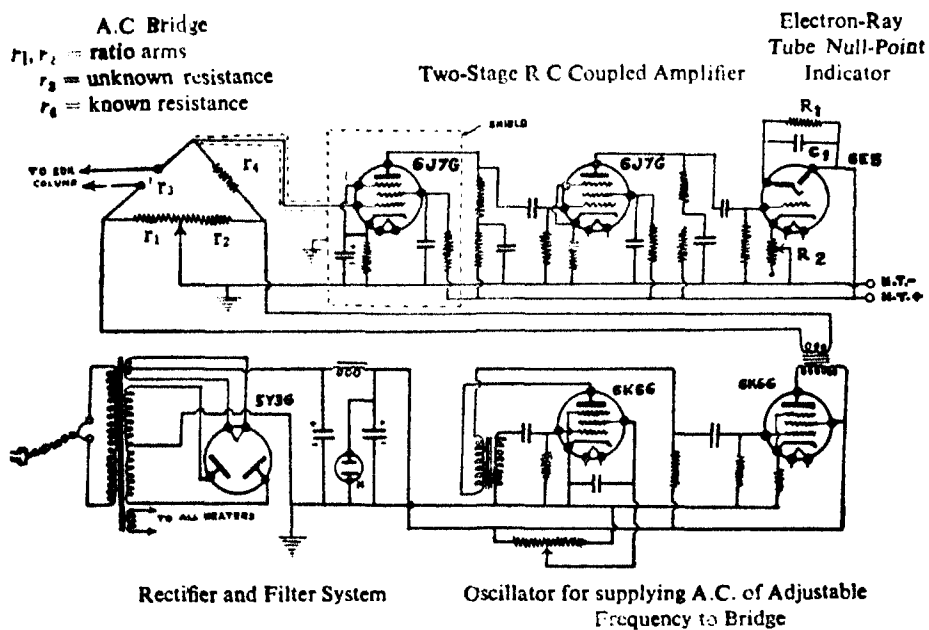


FIG. 52. Schematic circuit diagram of electron-ray tube null-point indicator for A. C. bridge

The details relating to this instrument have been published elsewhere. The apparatus has been employed for studying the movement of water and salts in soil under laboratory conditions. Some of the results of these experiments are summarised here.

The electrical conductivity of a porous medium like soil depends mainly on the following factors : (i) The degree of packing (ii) the amount of moisture present in soil particles and in the pore space (iii) the salt content of the soil and the fraction of it which goes into solution in the moisture contained by the soil and (iv) the material composing the soil.

Measurements show that the moisture content of the soil is the most important factor which determines its electrical conductivity. The next important factor is the degree of packing of the soil particles. The effect of the salt content becomes appreciable only after it goes into solution. In the laboratory experiments described here, the packing of the soil has been kept constant and the variations in the electrical conductivity as the combined effect of the capillary ascent of water from a reservoir below and the associated movement of the soluble salts is studied. Fig. 53 shows the simple experimental arrangement.

Soil ('Bari' soil of the Punjab) packed in the glass tube TT is held in position by a muslin piece covering the lower end which is immersed in the water reservoir R. The electrodes A and B are inserted suitably as shown. The terminals C and D are connected to the A. C. bridge. The electrical resistance of the soil between the electrodes A and B is measured at short time intervals while the advancing water front is as follows :

1. approaching A from below
2. at the electrode A
3. moving from A to B
4. moving upwards beyond B

Fig. 54 shows the electrical resistance of the soil between A and B plotted against various positions of the water front with respect to the electrodes. The resistances are plotted on a logarithmic scale. It may be observed that when the water front is well below the electrodes A and B the resistance is of the order of 20,000 Ohms to start with. When the water front touches A, the resistance is 14,000 Ohms; thereafter, when the water front moves from A to B, the resistance falls from the value at P to that at Q. When the water front has reached the upper electrode B, the resistance has a minimum value of 125 Ohms. When the water front moves beyond B, the resistance increases again along QR but remains steadily at about 1,000 Ohms for a number of hours after the water front reaches the top of the soil column and capillary movement has ceased. Thereafter, the resistance of the soil between A and B decreases very gradually over a number of days (not shown in the diagram).

The above results are easily explained on the basis of the movement of salts in solution (a) initially with the advancing water front where the concentration will be maximum. (b) thereafter until the cessation of capillary flow, with the moisture still moving upwards which will have less salt concentration and (c) finally, after capillary movement ceases, as the slow backward or downward diffusion of the salt from the top to the bottom of the soil column.

In another experiment matters were so arranged, that, as there was no soil above the upper electrode B, capillary movement stopped as soon as the water front reached B. As is to be expected, the resistance did not increase afterwards, but underwent only the slow further decrease associated with the downward diffusion.

#### *New Method of Estimating the Moisture Content of Soil in situ*

This instrument 59 which will be extremely useful to workers in Soil Physics and Agriculture has already been described on page 84. The problem of designing a portable type of this equipment has recently been solved and this design is under test.

#### *Electric Integrating Solarigraph (4)*

The importance of studying the light and heat energy received from the sun and the powerful influences these factors have on the weather and the growth and development of plants need hardly be emphasised. The sunshine data that are available at present are mostly that of duration of bright sunshine recorded with the Campbell-Stokes or other similar types of sunshine recorders installed at some of the meteorological observatories in India. For correlating the sunlight factor with the growth, development and yield of crops, some data on the total amount of radiation received and some information about the nature of the radiation are required.

A number of instruments are available for the measurement of the duration as well as the intensity of sunshine; but for estimating the total amount of radiation received during a given period, it becomes necessary to integrate the time-intensity curves of the records given by these solarigraphs. This is a laborious process even when performed with mechanical means like a planimeter, etc. The need for a solarigraph which automatically integrates the incoming solar radiation has, therefore, been felt for some time.

A new type of integrating solarigraph which makes use of electronic integrating and counting circuits and which registers the data on an electromagnetic counting mechanism has been developed by A. U. Momin in the Radiation Laboratory of the Agri-Met. Section at Poona.

A brief description of this instrument will be found in a recent paper (4). The instrument is calibrated by determining the amount of solar radiation per count of the counter of the instrument. This is being done at the Central Agricultural Meteorological Observatory, Poona, by taking comparative observations between this apparatus and the Moll Solarigraph.

#### *Other Instruments*

Besides the above, a number of other instruments like (a) the Cathode Ray Tube Spectrograph for studying the near infra-red absorption by the water vapour and other gases in the atmosphere, (b) a Thermal Repulsion apparatus and (c) other experimental techniques have been designed (4) successfully and this activity will, no doubt, continue at the Central Agricultural Meteorological Observatory at Poona.

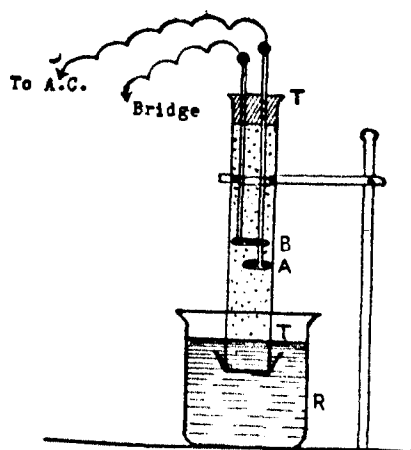


FIG. 53. Apparatus containing the soil sample through which water is ascending

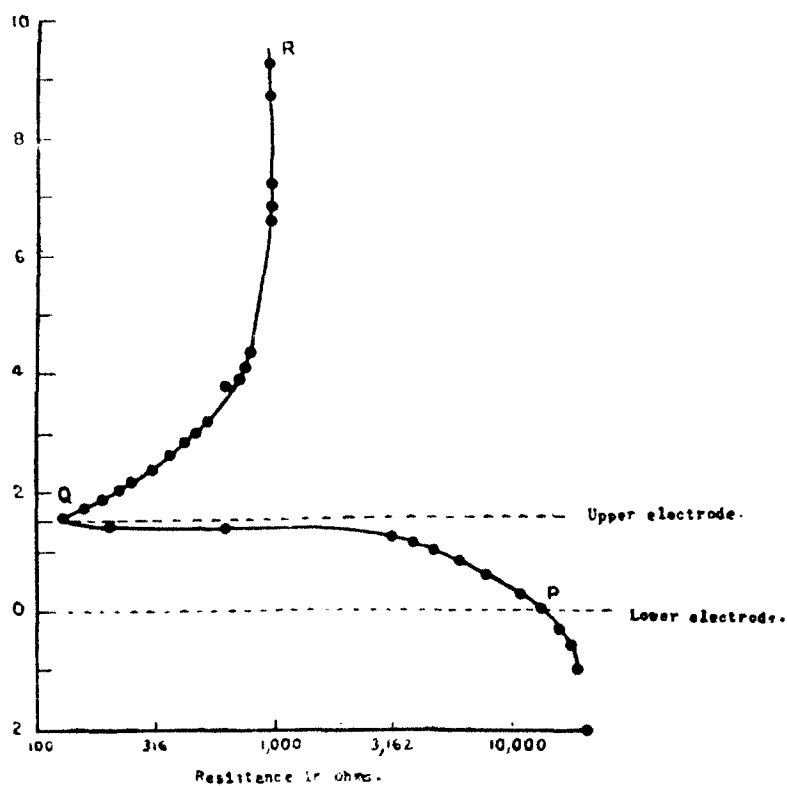


FIG. 54. Variation in the resistance of the soil between the electrodes with the upward movement of the water front

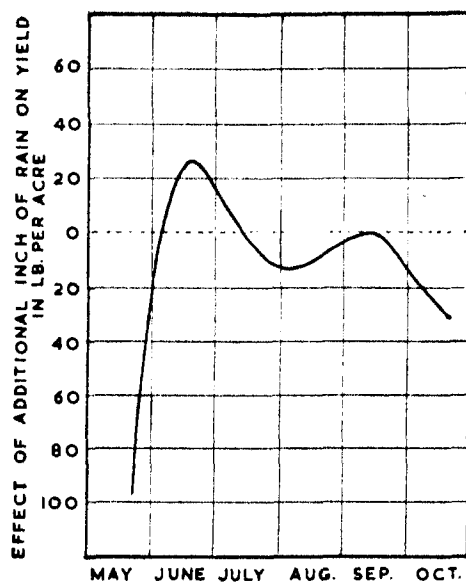


FIG. 55. Response curve (Akola-Jalgaon combined)

## CHAPTER III

### THE CO-ORDINATED CROP-WEATHER SCHEME

#### NATURE OF PAST CROP AND WEATHER RECORDS : THEIR LIMITATIONS

The system of recording and publishing (i) statistics of crop out-turns for revenue and other purposes and (ii) statistics of climatic elements like rainfall, temperature, etc., for weather prediction began in India about the time of the first Famine Commission, *i.e.*, towards the end of the seventies of the last century. The official estimates of (a) the acreage sown to crops in India (excluding the permanently settled areas of N. E. India) and (b) the yield per acre of different crops are available district-wise for the last 60 years or so. The acreage estimates are generally accurate but the estimates of yield per acre are known to be very unsatisfactory, based as they are on a system of subjective guess work by revenue officials. More recently, a number of experimental farms have been set up by the agricultural departments in the different States. With one or two exceptions where data are available for a longer series of years, these stations have recorded yield figures only for short periods. These data are no doubt more accurate than the district-wise estimates, but suffer from two serious defects from the view point of the agricultural meteorologist.

Firstly, the experimental stations have naturally concentrated their attention in the first instance on manurial experiments on crops and the effect of different cultural treatments, varieties of seed, intensities of irrigation, etc., so that no farm has maintained a uniform series of data which could be used for computing precisely the influence of weather on the crops. Secondly, even the average yield of a particular crop for the farm as a whole (average of all treatments etc.) is available only for periods which are much too short for detailed statistical analysis.

Coming to the meteorological data one finds that the records of rainfall are available for a much larger number of stations than the records of temperature or humidity which are maintained only at the small number of weather reporting observatories. Further, the observatories are usually situated in the compound of some public building, may be even in the heart of a city, so that the data would not be representative of the actual environment of the growing crop but would give only an estimate of the 'macro' or 'general' climate of the locality. Thus, we find that the agricultural and meteorological statistics, each collected by independent agencies and intended for different purposes show certain limitations in their use for establishing crop-weather relationships (75).

When work on Agricultural Meteorology was commenced in 1932, the Indian Council of Agricultural Research rightly stressed the shortcomings of the agricultural statistics of the past and emphasised the need for concentrating effort on the "biological" aspects with the object of evolving improved techniques for future crop and weather observations on scientific lines (79).

Before taking up the Co-ordinated Crop-Weather Scheme, we may summarise here some of the results of the work done on crop-weather relations relating to the cotton crop with the help of the past data.

## COTTON ACREAGE IN RELATION TO WEATHER

Two of the known causes of the fluctuations in the acreage under a crop from year to year are 'weather' and 'the market'. Weather at sowing time may influence the choice of the crop to be sown under the actual condition then prevailing. Irwin (120, 130) in his paper on 'Crop forecasting and the use of meteorological data in its improvements' has reviewed the work of various investigators and has suggested the possibility of predicting the acreage and the yield on the basis of weather; a method which, where adequate data exist, may be more accurate than those arrived at by the subjective methods used in the official forecasts of most countries.

Pioneer work in this field has been done in India by Jacob (121) and Unaker (122) with reference to wheat in the Punjab. The second controlling factor, *viz.*, prices prevailing during the pre-sowing season, has its influence on the acreage by influencing the mind of the cultivator as to the most profitable way of allotting his land to different crops.

Being one of the most important commercial crops, cotton was selected for investigation in the first instance, Kalamkar, Satakopan and Gopal Rao (104(c)) working at Poona have studied the effect of rainfall during the sowing season and the prices prevailing during the previous season on the acreage under cotton in each of the eight cotton growing districts of the Bombay State. A detailed discussion of their results will be found in a special publication of the Indian Council of Agricultural Research (104). A summary may be given here.

The acreage data extending over a period of about 50 years shows a general tendency to increase. This is mostly due to the increase in price of cotton; later, however, certain districts had begun to show a decreasing tendency, owing to fall in price. The co-efficient of variability of cotton acreage is least in Khandesh (8 per cent), Dharwar coming next with 13 per cent, other districts have variability within the range 15 to 30 per cent, except Ahmednagar which has the highest variability of 55 per cent. Prices of important varieties of 'Broach', 'Khandesh' and 'Dharwar' (average prices for the seven months January to July) are available from 1899 onwards. Corresponding varietal prices for the different cotton growing districts were used for computing their effect on the acreage under cotton.

Rainfall data of the pre-sowing months (*viz.*, May, June and July for Khandesh; June and July for Ahmednagar; June, July and August for Ahmedabad, Broach and Surat; and June, July, August and September for the Karnatak districts) were used for investigating the effect of rainfall on acreage.

Secular changes or trends in acreage, prices and rainfall were eliminated by fitting third degree polynomials to the respective series according to the method developed by Fisher (124, 125). The corresponding departures from these smooth curves from year to year, have been used for computing the correlation between the factors under consideration. From the correlation coefficients so obtained the relevant or significant factors were used for calculating the regression formulae, expressing the acreage  $A$  as a function of the price  $P$  (expressed as seers per rupee) and rainfall  $r$  ( $A$ ,  $P$  and  $r$  are departures from the polynomial

curves). These formulae along with the value of for the respective regression coefficients and of R the multiple correlation coefficient are quoted below :

TABLE 19

District	Regression equation	Value of		
		$T_p$	$t_r$	R
Ahmedabad . . .	$A = -202.00 P$	2.96	..	.49
Broach . . .	$A = -91.79 P - 1.55 r$ (June)	4.42	1.47	.67
Surat . . .	$A = -55.36 P - 0.92 r$ (July)	8.01	5.11	.89
Khandesh . . .	$A = -113.49 P + 33.47 r$ (May)	2.66	1.22	.50
Ahmednagar . . .	$A = +23.69 r$ (June)	..	4.81	.67
Belgaum . . .	$A = -52.78 P + 3.34 r_1$ (July)	..	1.86	..
	$+ 2.20 r_2$ (August)	1.70	0.91	.53
Bijapur . . .	$A = -144.51 P + 38.15 r$ (August)	1.58	2.84	.55
Dharwar . . .	$A = -136.83 P + 11.52 r$ (September)	3.39	1.98	.58

It will be seen that the acreage under cotton in the Ahmednagar District (sowing season June-July) shows a significant positive correlation with June rainfall, while the prices do not seem to have any influence. July and August rainfall in Belgaum and August rainfall in Bijapur (sowing season August to September) show a significant positive correlation with cotton acreage. As in Ahmednagar, the influence of price is not significant. Cotton acreage in the Surat District (sowing season June-July) shows a significant negative correlation with July rains. High prices are seen to increase the cotton acreage significantly in Ahmedabad, Broach, Surat, Khandesh and Dharwar.

#### COTTON YIELDS PER ACRE IN RELATION TO WEATHER

In contrast to the acreage data, as already pointed out, the data of 'yield per acre' are considered to be unreliable. They are not available directly from the official statistics but can be computed from (i) the 'standard yield' and (ii) the 'condition estimate'. The standard yield is defined as the average yield that can be expected over a certain area (e.g., a district) from a normal crop. The lack of exactitude in the definition of 'normal' (average yield on average soil in a year of average character) sets a limit to the accuracy of this measure\*. The 'seasonal factor' or 'anna value' or 'condition factor' is said to denote the ratio of the season's crop to the normal crop. This estimate (in terms of the standard of 12 or 16 annas) is essentially a visual one and has come in for severe criticism. The fact that the district condition figure is the average of the condition factors of a large number of villages for each of which an estimation is made separately may perhaps tend to decrease the error in the value for the district as a whole, to the extent to which over-estimation in some villages compensates under-estimation in others in each year. If the condition factors reported for a district over a fairly long series of years correctly represent the yields as percentages of the standard yield, then the average of these should not differ appreciably from 100. It is interesting to note that in none of the districts of the Bombay Province does the mean approach the value of 100, the actual variations being between 53 per cent and 76 per cent. This indicates a general tendency on the part of the estimator to

\*The problem of improving the precision of the 'standard yield' and of the crop out-turns is now making rapid progress in India due to the country-wide sampling surveys which are now becoming an annual feature.

under-estimate the condition of the crop. The detailed examination, in recent years, of the official forecasts, the returns of cotton ginned and pressed, and the trade statistics, by the Indian Central Cotton Committee has also shown that the yield of cotton has, in general, been under-estimated by the revenue authorities.

Among the meteorological factors, rainfall and air temperatures are prominent. Past information consists of (1) the rainfall recorded at the raingauge stations (10 to 20 per district) and (2) the temperature recorded at the weather reporting stations of the India Meteorological Department (rarely 1 per district and often 1 for a group of 2 or 3 districts).

Kalamkar, Satakopan and Gopal Rao (104-d) working at Poona, have discussed the yield per acre in relation to weather factors during the cotton season in another detailed paper for eight districts of the Bombay State. The series of yield data of cotton obtained by multiplying the standard yield by the seasonal factor, when tested for secular variations or trends according to Fisher's (123, 124, 125) method, indicate that there have been slow changes due presumably to the influence of such counteracting factors as intensive cultivation, land under margin of cultivation being brought under the plough, introduction of improved varieties and variations in the standard of estimation. The meteorological data were also similarly treated for secular variations. The corresponding year to year fluctuations of the yield and weather data, after the elimination of trends, if any, were then correlated. The regression equations expressing the departures (after eliminating trend) of  $Y$ , the yield as a function of the departures of rainfall  $r$  and of maximum temperature  $t$  are given in Table 20.

TABLE 20

*Ahmedabad* ( $R = .60$ )

$$Y = +0.602 r_2 + 1.760 r_4 - 1.515 t_4 - 1.463 t_5 - 0.505 t_6 - 2.183 t_7.$$

*Broach* ( $R = .45$ )

$$Y = +0.699 r_2 + 1.697 r_3 + 1.564 r_4.$$

*Surat* ( $R = .53$ )

$$Y = +.271 r_2 + .386 r_3 + 3.668 t_0 - 2.074 t_3 - 1.393 t_5.$$

*Khandesh* ( $R = .69$ )

$$Y = +.217 r_2 + 0.757 r_4 + 3.401 t_0 - 0.379 t_4 - 3.654 t_5 + 1.518 t_6.$$

*Ahmednagar* ( $R = .60$ )

$$Y = +2.644 r_1 + 1.415 r_4 - 3.668 t_2 + 0.346 t_4 - 1.198 t_5.$$

*Belgaum* ( $R = .65$ )

$$Y = +2.142 r_4 + 0.739 r_5 - 1.766 t_5 - 0.134 t_6 - 1.484 t_7.$$

*Bijapur* ( $R = .83$ )

$$Y = +2.528 r_1 + 4.189 r_2 + 2.897 r_3 + 2.876 r_4 + 1.230 r_5 - 0.621 r_6$$

*Dharwar* ( $R = .57$ )

$$Y = +1.279 r_1 + 2.770 r_3 + 2.852 r_4 + 2.337 r_5.$$

N.B.— $Y$ ,  $r$  and  $t$  are deviations from the mean (after elimination of trend, if any). The suffix of 0, 1, 2, 3, etc., represent months commencing from May.

The yearly fluctuations in the yield per acre of cotton in these cotton growing districts seem to be significantly influenced by the rainfall as well as the maximum temperature prevailing during the growing season. Rainfall gives a positive correlation with yield. High day temperatures in May in the Khandesh and Surat Districts show a significant beneficial effect on yield. Such beneficial effect of temperature in May is also indicated in the Ahmedabad District. On the other hand, day temperatures, above the normal during the flowering and bolling period of cotton show an adverse effect on the yield.

In attempting to predict the expected acreage or the yield per acre in a district, by the statistical method referred to above it must be pointed out that the prediction would consist of two parts, *viz.*, (1) the yield as indicated by the smooth curve (polynomial) fitted to the series (to represent a moving average) and (2) the deviation of the expected yield from this polynomial value as computed from the regression formulæ of Table 21.

It is to be noted, however, that the values of the smooth polynomial curves at the beginning and end of the series will not be accurate. This is a serious difficulty.

#### ANALYSIS OF YIELD DATA RECORDED AT EXPERIMENTAL FARMS

The yield records maintained by experimental farms are more reliable than the district statistics. Generally speaking, the records are results of experiments intended to show up the effects of manures, variety, cultural methods, intensity of irrigation, etc. Nevertheless, it is interesting to note that, whenever the same experiment has been repeated over a series of years, the analysis of variance does bring out the fact that the variability between years (which is a measure of the direct or indirect influences of weather) is of the same order of magnitude as the variability due to treatments. As an example selected quite at random, the following table is quoted from page 125 of 'Experiments in manuring crops in the Bombay Presidency, 1896-1931' by Rai Bahadur D. L. Sahasrabudhe [Government Central Press, Bombay, 1934].

TABLE 21. ANALYSIS OF VARIANCE OF COTTON YIELDS AT DHARWAR—6 TREATMENTS IN 1921, 1923, 1925, 1927, 1929 (JOWAR—COTTON—ROTATION)

	Degrees of freedom	Variance	$\frac{1}{2} \log. V$
Treatments* . . . . .	5	456.8	3.0598
Years . . . . .	4	1705.7	3.7167
Error . . . . .	20	28.3	1.6694

\*Treatments were as follows: 2.5 tons of F. Y. M. per acre every year.  
 2.5 tons of F. Y. M. per acre Second year.  
 5 tons of F. Y. M. per acre Second year.  
 10 tons of F. Y. M. per acre Second year.  
 10 tons of F. Y. M. per acre Fourth year.  
 15 tons of F. Y. M. per acre Second year.  
 and no manure.

The above is just one of several hundreds of similar experiments carried out in various farms in India. While thus confirming the significance, indeed the great importance of the year to year variations of weather, these experiments do not tell us exactly how the weather has influenced the crop. For this purpose, yield data recorded with the same variety and cultural treatments over a long series of years together with weather data recorded at the same spot will be necessary. Unfortunately, such ideal information is not available for past years. There are, however, fairly long series of yield data representing the entire farm's average over many plots, treatments, etc., and rainfall data at a few farms. Much attention has been and is being paid to the analysis of these data as they are the best available at present. The results of one typical investigation are summarised below.

Kalamkar and Satakopan [74, 104(a)] working at Poona, have studied the cotton yields at Akola (Berar) and Jalgaon (East Khandesh), both stations representing adjacent cotton growing tracts with much similarity of soil, climate and cultural methods. Cotton is sown by the second week of June, usually after the first fall of 2 inches of rain. The period of quickest growth is August-September. The crop is ready for first picking in October. About four pickings are obtained during the growth period of the crop. The Khandesh crop is early by about a fortnight. The yield data of Akola are available for 28 years from 1907-08 onwards and of Jalgaon for 23 years from 1913-14. The two series did not show any significant secular changes. In studying the effect of rainfall on the yield of cotton the period 22nd May to 23rd October is considered. This period is divided into 31 sub-periods, each of five days, an interval sufficiently fine to represent the rainfall distribution and to study its effect on the growth of the crop and the agricultural operations, such as interculture, weeding, etc.


The 31- five-day rainfall figures for each year were fitted with a polynomial of the 5th degree and a set of six constants  $a'$ ,  $b'$ ,  $c'$ ,  $d'$ ,  $e'$ , and  $f'$ , is obtained to represent the distribution. These constants are later used as independent variates with which the crop yield is correlated to obtain a regressional integral according to the method developed by Fisher (124, 125). The mean values of the rainfall distribution constants for Jalgaon and Akola are seen to be similar. The series of yields for the two stations when correlated with the respective rainfall distribution constants lead to the following regression equations, expressing departures of the yield  $Y$  in terms of the distribution constants  $a'$ ,  $b'$ ,  $c'$ ,  $d'$ ,  $e'$  and  $f'$

$$\text{Akola } Y = -0.432 a' + 0.328 b' - 1.285 c' + 1.317 d' - 3.033 e' + 2.067 f' \dots\dots (1)$$

$$\text{Jalgaon } Y = -0.149 a' + 0.191 b' - 0.802 c' + 1.573 d' - 1.399 e' + 2.178 f' \dots\dots (2)$$

Combining the data of Akola and Jalgaon into a single series we have :

$$Y = -0.240 a' - 0.100 b' - 0.856 c' + 0.939 d' - 2.040 e' + 1.447 f' \dots\dots (3)$$

From the regression coefficients and the corresponding orthogonal functions of time, continuous curves have been drawn showing the average effect per acre corresponding to an additional inch of rain at different times during the growing season. Fig.  shows the curve for Akola-Jalgaon combined.

The curve shows an adverse effect for an additional inch of rain in the fourth week of May. Heavy and continuous rainfall in the latter half of July and the first half of August affects the yield adversely, presumably as it favours weeds and water logging and delays weeding and interculture operations. Heavy rain at the end of September or the early part of October damages the cotton crop by knocking off the bolls. The adverse effect of rain in the fourth week of May is not surprising when it is recalled that in the investigation of the effect of monthly rainfall and temperature on cotton yields in the districts of the Bombay Province, it was also found that high day temperature in May (this is associated with scantiness or absence of rain) had a beneficial effect on yield in the Districts of Khandesh, Surat and Ahmedabad. An adverse effect of rainfall in May and June on cotton sown in the following July or August at Gazcira has been reported by Crowther (126). He attributes this effect to the washing away of the nitrates formed in the soil. It may be mentioned that fortnightly estimations of the total nitrogen in the soil at different depths in the bare plot of the Central Agricultural Meteorological Observatory have been made by Mallik during a few years [107 (1939-40)]. These data (unpublished) show that the first showers of the season do cause a drop in total nitrogen in the soil, due to leaching. The adverse effect has been also attributed to the possible interference with the soil cracks (Lambert and Crowther) (127) by rainfall which reduces the rate of drying off of the soil and closes the sub-soil cracks, thus preventing adequate sub-soil aeration or water penetration.

It is interesting to note that the response curves showing the effect of an additional inch of rain on yield appear more or less to agree with the usual impressions of the cultivators of this tract. In this connection a paper on 'Cotton Prospects on the Nagpur Agricultural College' by McDougall (128) is of interest.

From the foregoing, it will be clear that any crop-weather relationships that may be established with the help of crop and weather data recorded carefully under expert supervision at Government Experimental farms are likely to be of wider application to the tract (district or group of districts) which it represents. It is therefore the duty of present workers, to institute a system of crop weather observations at selected centres in the country so as to ensure the accuracy and sufficiency of future data. This topic is dealt with in the following pages.

#### THE CO-ORDINATED CROP-WEATHER SCHEME

The collection of systematic detailed information relating to the weather as well as the life history of the crop during the growing season at selected experimental farms, according to a common plan is an urgent matter. This has been organised by the Director of Agricultural Meteorology according to the Co-ordinated Crop-Weather Scheme (78, 79) as approved and given effect to by the Indian Council of Agricultural Research and also the Indian Central Sugarcane and Cotton Committees. A brief outline of this 'Scheme' is given in this section. (See also Agri-Met Technical Circular No.-50.)

##### *The Grower's Year (129)*

The times of planting and harvesting a crop will vary with the locality. We may consider, first of all, the time intervals into which the season should be divided. It has long been realised that the month is too large a period to serve as a time unit in studies on the development of crops in relation to the intensity and distribution in time of the

relevant weather factors. To ensure the adoption by different workers of a common plan in this matter it is advisable to divide the calendar year into 'standard weeks' and group these into 'standard periods'. The proposed scheme is shown in Table 22 below :

TABLE 22. THE STANDARD WEEKS OF CALENDAR YEAR

Period No.	Week No.	Dates	Period No.	Week No.	Dates
I	1	January 1—7	VII	27	July 2—8
	2	Do. 8—14		28	Do. 9—15
	3	Do. 15—21		29	Do. 16—22
	4	Do. 22—28		30	Do. 23—29
	5	Do. 29—4 February		31	Do. 30—5 August
II	6	February 5—11	VIII	32	August 6—12
	7	Do. 12—18		33	Do. 13—19
	8	Do. 19—25		34	Do. 20—26
	9	Do. 26—4 March*		35	Do. 27—2 September
III	10	March 5—11	IX	36	Sept. 3—9
	11	Do. 12—18		37	Do. 10—16
	12	Do. 19—25		38	Do. 17—23
	13	Do. 26—1 April		39	Do. 24—30
IV	14	April 2—8	X	40	October 1—7
	15	Do. 9—15		41	Do. 8—14
	16	Do. 16—22		42	Do. 15—21
	17	Do. 23—29		43	Do. 22—28
	18	Do. 30—6 May		44	Do. 29—4 November
V	19	May 7—13	XI	45	November 5—11
	20	Do. 14—20		46	Do. 12—18
	21	Do. 21—27		47	Do. 19—25
	22	Do. 28—3 June		48	Do. 26—2 December
VI	23	June 4—10	XII	49	December 3—9
	24	Do. 11—17		50	Do. 10—16
	25	Do. 18—24		51	Do. 17—23
	26	Do. 25—1 July		52	Do. 24—31**

\*In leap years the last week of period II will be February 26th to March 4th i. e. 8 days instead of 7.

\*\*Last of week period XII will have 8 days, 24th to 31st December.

The grower's year will vary from crop to crop and also with locality. For example, in North India, the sugarcane grower's year may commence with period No. III, week No. 10 of the calendar year and end with period No. II, week No. 6 of the next calendar year. Whatever be the actual dates of sowing and harvesting of any crop, these dates can be assigned to standard periods and week numbers of the calendar year. Our aim is to record as precisely as possible how the climatic factors of each of the weeks of the grower's year affect the growth and the yield of the crop under observation.

### *Crop Observations*

The observations should be taken on fields situated close to the meteorological station at the farm. It is desirable that there should be two varieties of crop under observation with six replications. In the case of wheat one of the two varieties should be Pusa (N.P. 4). The common or local method of cultivation and rotation should be followed on these plots. Soil characteristics, previous cropping, date of sowing and germination, date of ear emergence (*i.e.*, the date on which about 50 per cent of the plants have fully emerged ears), the date of harvest, the total yield, manuring, cultural operations including irrigation with dates and quantity if possible and name of variety should be noted together with information regarding incidence and intensity of diseases, pests, etc. It will also be necessary to maintain a crop-weather diary in which brief notes on the weather and the impressions of the observer regarding the effect on crops in general are noted from time to time.

### *Sampling Observations*

The sampling observations are simply quantitative observations such as plant, shoot and ear number per unit length, height of shoot, etc., taken according to the specified sampling technique. The sampling should be done afresh each time, to avoid any selective bias on the part of the observer. These observations should be made at short intervals of time, once a week up to the time of ear emergence and once a fortnight thereafter. Such quantitative measurements of the plant's growth enable us to determine the principal events which mark the progress of the crop from germination to maturity. Besides being useful and necessary for studying the effect of meteorological factors on growth and yield of crop, the data will also be useful for investigating the relation, if any, between the growth history of the crop up to a given date and the final yield. In other words, we may try to use the plant itself as an indicator of its possible yield at the end of the season and thus explore the possibility of crop forecasting. It must be observed, however, that the results of the sampling observations on the experimental plots may not by themselves provide a complete crop estimation or a forecasting scheme. It will be advantageous to know also the yields on cultivators' plots in the neighbouring area in order to investigate the relation of these to the yields and other quantities determined on the experimental plots.

### *General Scheme for Sampling Observations*

The size of the plot will be 1/80 acre for wheat, 1/40 for jowar and cotton, 1/100 for rice, 1/20 for sugarcane. The size and structure of the "sampling unit" for the different crops are given below:

*Wheat*: A sampling unit is a 4 ft. length made up of four parallel foot lengths on adjacent rows. Three such samples may be taken from each half of the plot, giving 36 such samples for the six replications of each variety.

**Jowar (Sorghum) :** The sampling unit is a 8 ft. length made up of two parallel 4 ft. lengths in adjacent rows. Three such samples may be taken from each half of the plot giving 36 such samples for the six replications of each variety.

**Rice:** (a) For irregular or broadcast sowing a sampling unit will be a two-foot square frame. (b) When the crop is transplanted in rows of bunches the structure of the sampling unit will be as follows:—

First row	O X X X O Omit	X X X O Omit	X X Omit
Second row	X X O Omit	X X X O Omit	X X X O Omit

O means bunch under observation.

X means bunch not under observation.

Thus each sample will consist of 3 bunches from each of two adjacent rows. Three such sampling units may be taken from each half of the plot giving 36 such samples for six replications of each variety.

**Cotton :** The structure of the sampling unit will be an 8 ft. length made up of two parallel 4 ft. lengths in adjacent rows. Three such sampling units will be taken for each half of the plot giving 36 such samples for the six replications.

**Sugarcane :** The sampling unit will be an 8 ft. length and for developmental studies the two clumps nearest to the ends of the rod and falling within the sampling rod would be under observation. Three such sampling units will be taken from each half of the plot, the total number of clumps under observation from each variety with six replications being  $(2 \times 3 \times 2 \times 6 = 72)$  seventy-two.

### Periodical Growth Observations

The periodical observations are to be taken by the sampling process suggested above.

In the case of wheat, *jowar* and rice, germination counts, number of plans and shoots, heights of the tallest shoot of the end plants of each ultimate unit (namely, one foot for wheat and four feet for *jowar*) in the case of wheat and *jowar*, and the corner plants in the case of broadcast rice, maximum growth rate in height, ear emergence, number of ears, yield as determined by sampling, and total yield of plot should be recorded. 1,000—corn weight (in gms.), protein content, and moisture percentage in grain should be recorded in duplicate for each variety. In the case of transplanted rice the shoot nearest to the observer in each bunch should be selected for height measurement.

In the case of cotton the number of plants in each 4 ft. length, the height of the main stem of plants at each end of the 4 ft. length, maximum growth rate in height, number of monopodial and sympodial branches, total number of bolls picked from each 4 ft. length sample, weight of *kapas* from the samples and from 100 bolls picked from the rest of the plot (taken in duplicate for each picking), yield as determined by sampling, total yield of the plot, ginning percentage and halo length should be recorded.

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\*The line of division being parallel to the rows of the plot.

The following developmental observations of sugarcane should be recorded on the clumps selected:

1. Germination counts should be taken daily from the date of appearance of the first seedling after planting till germination appears to be completed, *i.e.*, for about three weeks.

2. Total number of canes in the clump (*i.e.*, the mother cane plus the tillers).

3. *Leaf*—(i) number of fully expanded green leaves in the tallest cane of the clump.

(ii) (a) measurements of the breadth (b) of each of the leaves of the above cane at the widest point, and the length from tip to the collar.\*

4. *Height of the cane*.—The height of the tallest cane of the clump should be measured from the surface of the ground (proper adjustment being made for the depth of the furrow or the height of the ridge with reference to the surface of the ground) to the highest visible transverse leaf mark. The maximum growth rate in height should be noted. At the time of harvest, however, the height of the millable canes will be the height up to the transverse mark of the topmost leaf sheath which can easily be separated from the cane by gently pulling the leaf blade.

5. *Circumference*.—The circumference of the tallest cane of the clump will be measured by a cloth tape at  $\frac{1}{4}$ ,  $\frac{1}{2}$  and  $\frac{3}{4}$  of the height of the tallest cane of the clump periodically during the season.

6. *Number and weight of canes at harvest*.—For this purpose the number of canes actually included in the sampling unit, *i.e.*, 8 foot length of the row (excluding any canes of the clumps under observation falling outside the sampling rod) and the weight of these canes in lbs. will be recorded. The actual weighing should be correct to 10 gm. While making these weighings, the weights of the canes in the two clumps at either end of the sampling unit should also be recorded separately.

### *Brix Reading*

Brix reading may be taken, where possible, with the help of the juice sampler and a hand refractometer (without removing the canes from the field) once every fortnight when the canes start ripening *i.e.*, about  $2\frac{1}{2}$  to 3 months before harvest. To prevent the incidence of red rot etc., at the punctured spots, these should be plugged with sterilised wax immediately after sampling the juice. For this purpose the juice from the middle internode of the tallest cane from each clump under observation should be used.

At the time of harvest, the total number and weight of canes obtained from each plot may also be separately recorded. It would be advantageous to record the outturn of 'gur' obtained from the plots in which sampling observations were taken to study the variation, if any, of the "gur" to cane ratio.

*N. B.*—In the case of all the crops, a set of the usual growth observations should be recorded at the time of harvest on the samples selected for harvest.

\*The area of the leaf is given approximately by  $t/2b \times l$ .

### *Pests and Diseases*

General observations on the occurrence and the intensity of attack of pests like borers and pyrilla and diseases such as smuts, red rot, mosaic, etc., as well as their effects on the growth and yield of the crop should also be recorded. This part of the work may require co-operation of the local entomological and mycological staff.

The technique to be adopted for estimating the intensity of pests and diseases is specified in Agri-Met. Technical Circulars 51 and 52.

The sampling observations should be recorded in standard forms which will be provided.

### *Layout of the experimental plots for crop-weather observations*

These details are given in Agri-Met. Technical Circular No. 50 and are summarised in the attached diagram (Fig. 56).

The size of the plots in blocks ABC and XYZ and their shape in respect of the different crops will be as follows :

Crop	Plot dimensions : Along the rows × Across the rows (excluding borders)	*Border all round the plot (not to be in- cluded for observation of growth or yield)	Dimensions of each block ; e. g., A,B,C, etc. (Total length × breadth including the borders)
Wheat . . . . .	24' × 24'	2'	176' × 64'
Jowar and Cotton . . . . .	36' × 30'	3'	228' × 96'
Paddy . . . . .	21' × 21'	1'	142' × 50'
Sugarcane . . . . .	46' × 48'	3'	336' × 116'

### *Meteorological Observations*

The meteorological factors to be observed are rainfall, air temperature and humidity, soil temperature and moisture, wind, evaporation, cloudiness and the incidence of special weather phenomena like thunder-storms, hail-storms, frost, high winds, floods, etc. For this purpose suitably equipped meteorological stations are necessary at experimental farms. As a result of the general awakening in agricultural research in recent years, most of the States of India are taking an increasing interest in the study of weather in relation to agriculture and have arranged or are beginning to arrange to equip their experimental farms with standard meteorological equipment. Since the opening of the section of Agricultural Meteorology at the Poona Meteorological Office in 1932, the India Meteorological Department has also found it possible to give increased and specialised attention to the subject. The number of farm observatories is gradually increasing; some 60 of these are expected to be sufficiently well equipped to be able to take part in a scheme of *crop-weather observations*. The records of meteorological observations at the experimental

\*In addition to the above border around each plot, additional border around the whole block should be provided. The width of this border will be 4 ft. for wheat, 6 ft. for jowar, cotton and sugarcane and 2 ft. for paddy.

farms should include both daily observations at specified hours and also notes on abnormal or destructive phenomena. A scheme for regular observations is given below:

*Scheme for Meteorological Observations to study Crop-weather Relationships at Experimental Farms*

At experimental farms engaged in crop research, it is advisable to start with a minimum\* of the meteorological equipments and observations, additions and alterations in these being made in the light of actual experience later on.

*Site*

The site of the observatory should be a bare plot 60 yds. by 40 yds. with its longer side running north to south, at the centre of the farm and surrounded by the experimental plots in which the crops under investigation are grown. The site should be closed with a barbed wire fencing and should be easily accessible during rains; water logging should be avoided. The above size of the observatory site provides for expansion in the meteorological work later on. The site should be chosen once for all.

*Minimum meteorological equipment\*\**

- |  |   |
|--|---|
| (i) Dry bulb thermometer   | { To be installed inside a Stevenson Screen<br>(facing north and with its base 4 ft. above<br>ground)         |
| (ii) Wet bulb thermometer  |   |
| (iii) Maximum thermometer  |   |
| (iv) Minimum thermometer   |   |
| (v) Piche evaporimeter   |   |
| (vi) Robinson anemometer   | { To be installed on pillars with anemometer<br>cups and vane at the average height of<br>10 ft. above ground |
| (vii) Windvane   |   |
| (viii) Ordinary rain gauge   |   |
| (ix) Grass minimum thermometer                                       |   |
| (x) Sunshine recorder ***  |   |
| (xi) Soil thermometers for 5, 15 and 30 cms. depths                  |   |
| (xii) Assmann Psychrometer for recording micro-climatic observations |   |
| (xiii) U.S.A. standard open pan evaporimeter                         |   |

*Time of Observations*

As experimental farms are concerned with the study of the extreme and mean values of air temperature, humidity, etc., 7 a.m. and 2 p.m. (mean local time) are the most suitable hours of observations, as they represent approximately the epochs of minimum and maximum temperatures respectively. Rainfall should be recorded at 8.30 I.S.T. If the above times are brought into use, no observations need be recorded at 8 a.m. (unless the station is also one of the network of weather telegraphing stations of the India Meteorological Department).

\*At present owing to the difficulty in obtaining meteorological instruments, this is unavoidable.

\*\*Detailed specifications, approximate prices, names of firms stocking meteorological instrument etc., may be obtained from the Director, Agricultural Meteorology. If the instruments are sent to Poona they will be calibrated and returned. Assistants deputed to the Meteorological Office will be trained in installing meteorological instruments, in recording observations and reducing and analysing the data.

\*\*\*Chart of the sunshine recorder should be changed daily after sunset.

### *Routine Observations*

*At 7 a.m.*—Dry bulb, wet bulb and maximum\* and grass minimum temperatures\*\*, soil temperatures at 5, 15 and 30 cms. depths, wind direction and anemometer readings at 7 a.m., evaporation during past 24 hours, and weather remarks. 'Micro-climatic' observations in the 'open' and in the crop, *i.e.*, readings of the Assmann Psychrometer (ventilated dry and wet bulb readings) at the standard levels only (these levels would vary with the crop; *e.g.*, the levels will be surface, 1, 2 and 4 ft. for rice, wheat and cotton and surface, 1, 4, 8 and 12 ft. for *jowar* and sugarcane) may be recorded at stations equipped with an Assmann Psychrometer.

*N. B.*—Rainfall is to be recorded at 8.30 I.S.T.

*At 2 p.m.*—Dry bulb, wet bulb, minimum temperatures, soil temperatures, at 5, 15 and 30 cms. depths and 'micro-climatic' observations in the 'open' and in the crop.

### *Special Periodical Observations of Soil Moisture*

Estimation of soil moisture should be made at weekly or fortnightly intervals at depths of 3, 6, 12, 18 and 24 inches in the bare observatory plot. In the crop fields moisture estimates may be made only at the 6, 12, 18 and 24 inch depths on the dates prior to the dates of irrigation; if un-irrigated, the interval may be fortnightly.

### *Frequency and Intensity of Irrigation*

The dates and estimated intensity of irrigation in acre inches should be recorded.

### *Tabulation*

The tabulations of the data should be maintained on standard CWS forms which will be provided.

## SOME SPECIAL FEATURES OF THE CROP-WEATHER SCHEME

### *Micro-climates*

In Chapter II, pages 58-75, we have already seen that plant communities develop their own characteristic micro-climates. The Crop-weather Scheme includes measurements of the micro-climate.

The sampling technique for recording the periodical developmental observations on short crops of the temperate regions, like wheat, oats, barley, had already been evolved in Britain by Prof. Fisher and his co-workers (131). In India we had to try out and evolve the sampling techniques suitable for paddy (transplanted in bunches), *jowar* and sugarcane (tall crops) and cotton (a bushy crop). This pioneering work for evolving sampling techniques for our tropical crops has involved a series of investigations undertaken by our staff and research students at Poona. Reference may be made here to the following work :

1. Kalamkar, Gadre, Mallik, Satakopan and Gopal Rao (73, 83, 92) on sampling technique for wheat

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\*The maximum thermometer should be set after reading and the test readings of this instrument and of the dry bulb thermometer recorded.

\*\*The grass minimum thermometer should be read after all other observations have been recorded ; after reading the instrument it should be kept indoors and exposed again after setting only about 4 or 5 P. M. This precaution is very essential to prevent the spirit column from breaking.

The minimum thermometer should be set after reading and the test readings of this instrument and of the dry bulb thermometer recorded.

2. Kalamkar, Kadam, Satakopan, Gopal Rao and Sreenivasan, (77, 90, 92) for paddy
3. Mallik, Sreenivasan, Gopal Rao and Pimpalwadkar (80, 81, 92) and others for jowar
4. Mallik, Sreenivasan, Ramabhadram, Borole and others (82, 132, 133, 134, 135, 92) for sugarcane
5. Arakeri (87) for Bajra
6. Sreenivasan, Chaugale and others (85, 136, 137, 92) for cotton.

Further investigational work of this exploratory nature is continuously in progress at Poona and in December 1949 the whole subject of sampling for growth, insect pests, diseases etc., was discussed at a symposium arranged by the Indian Society of Agricultural Statistics (92). It was interesting to note that techniques adopted for the co-ordinated Crop Weather Scheme are quite satisfactory as confirmed by recent complete enumeration experiments conducted at Poona.

#### *Data recorded under the Scheme*

It may be mentioned that crop and weather data from a network of selected crop-weather stations situated in experimental farms in India have begun coming in regularly during the last few years. These data are being scrutinised and analysed year by year (108, 109, 110). A critical review of the results obtained will be possible only after data accumulate for a sufficient number of years.

#### THE COMMISSION FOR AGRICULTURAL METEOROLOGY OF THE WORLD METEOROLOGICAL ORGANISATION

The first meeting of this commission met in Paris in 1953. The present writer who represented India at this meeting, was the Chairman of the Committee which dealt with the technical and scientific items on the agenda and he had a valuable opportunity for bringing to bear on the discussions, resolutions and technical regulations relating to agricultural meteorology, the experience and knowledge gained by the Indian workers in this field.

The above commission is responsible for guiding member countries on all technical and scientific aspects of agricultural meteorology. Besides drawing up detailed technical regulations to guide the research work on this subject, the commission has also taken up the problem of preparing a Manual of Agricultural Meteorology.

BLOCKS AND SUB-BLOCKS  
FOR BULK YIELD.

## BLOCKS AND PLOTS FOR ESTIMATION OF PLANT DISEASES AND PESTS

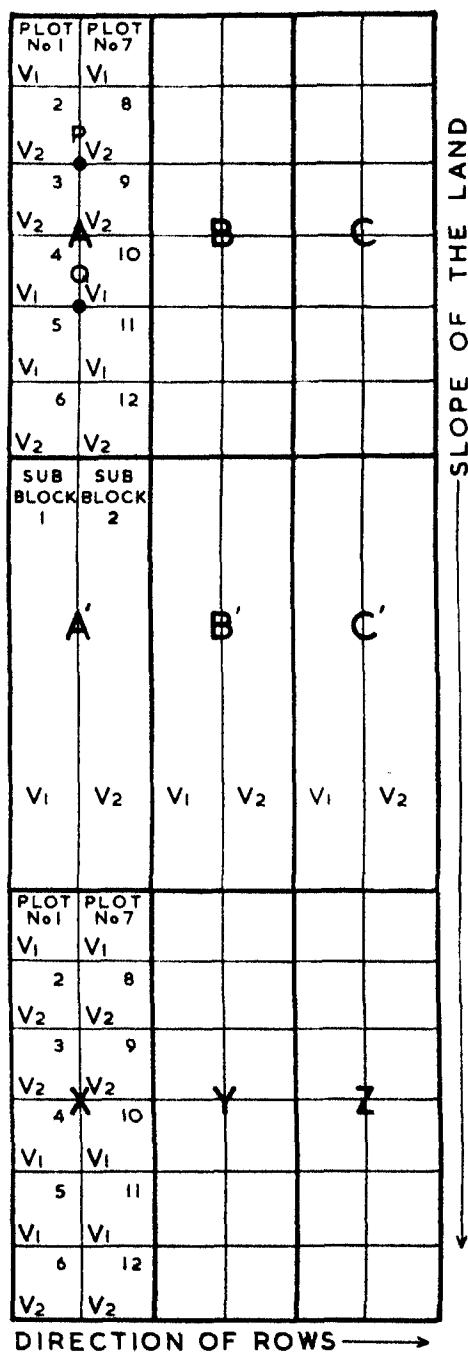


FIG. 56. Layout of experimental blocks and plots for the crop weather observations,

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- 92 A symposium on "Crops and Weather" was opened by Ramdas L. A. at the annual meeting of the Indian Society of Agricultural Statistics on the 31st December 1949; the following papers were presented by various workers:
  - (a) Kalamkar R. J. on "Crops and Weather"
  - (b) Mallik A. K. on "Complete harvest experiments on wheat"
  - (c) Sreenivasan P. S. on "Recent complete enumeration experiments on cotton"
  - (d) Ramabhadran V. K. on "Complete enumeration experiments on sugarcane"
  - (e) Gadre K. M. on "A complete micro-climatic Survey of a sugarcane field"
  - (f) Bhat N. R. on "Crop-weather Studies as an aid to the breeding and introduction of crop plants"
  - (g) Mehta K. C. on "Cereal Rusts"
  - (h) Pradhan S. on "Estimation and Study of pest incidence"
  - (i) Pradhan S. on "Integration of Weather Effects"
  - (j) Panse V. G. on "Forecasting of yield of cotton with particular reference to quantitative observations on the plants"
  - (k) Sukhatme P. V. on "Sampling Surveys and crop cutting experiments for the estimation of crop yields"
  - (l) Koshal R. S. on "Crop cutting experiments in relation to crop forecasting"
  - (m) Ananthapadmanabha Rao A. on "Long period trends in crop and weather data"
  - (n) Ramdas L. A. and Mallik A. K. on "Objective assessment of the crop outlook in India at intervals during the growing season, based on the progress of weather week by week"
  - (o) Govindaswamy T. S., Pimpalwadkar P. V. and others on "Studies on sampling for the estimation of growth and yield of *jowar*"
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- 102 Ramdas L. A., Govindaswamy T. S. and Pimpalwadkar P. V. (1950), *Bombay Farmer*
- 103 Ramdas L. A. (1935), Report of the Conference of Empire Meteorologists, contains note summarising the work done in India on the following topics:
  - (a) Correlation of general crop observations with meteorological data (p. 173)
  - (b) Measurement of evaporation (p. 180)
  - (c) Soil temperature (p. 160)

- 104 Supplement to the Annual Report of the Agricultural Meteorology Section, for the year ending 21st August 1935 contains the following papers:
  - (a) "The effect of rainfall on the yield per acre of cotton at the Government Experimental Farm, Akola (Berar)" by Kalamkar R. J. and Satakopan V.
  - (b) "Notes on the analysis of yields of crops at the Government Experimental Farms in the C.P. and in the Bombay Presidency" by Kalamkar R. J. and Satakopan V.
  - (c) "Influence of weather and prices on the cotton acreage in the Bombay Presidency" by Kalamkar R. J., Satakopan V. and Gopal Rao S.
  - (d) "Influence of weather on the yield per acre of cotton in the Bombay Presidency" by Kalamkar R. J., Satakopan V. and Gopal Rao S.
- 105 Ramdas L. A. (1937), Proc. of the Crop and Soil Wing of the Board of Agriculture and Animal Husbandry; note on "crop protection from the effects of weather"
- 106 Report of the International Commission on Agricultural Meteorology (1937), contains the following notes by Ramdas L. A.
  - (a) "Report on simple methods of measurement in Agricultural Meteorology"
  - (b) "Report on invisible condensation"
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  - (b) year ending 21st August 1934
  - (c) year ending 21st August 1935
  - (d) period 22nd August 1935 to 31st March 1937 and thereafter regularly
  - (e) for each year ending 31st March for the years 1938 onwards
- 108 Annual Reports of the Co-ordinated Crop-Weather Scheme (Indian Council of Agricultural Research) for each of the years ending 31st March 1946 onwards
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## ERRATA

to "CROPS AND WEATHER IN INDIA" by *L. A. Ramdas*; published by I.C.A.R.

- Page 7. .. Read "Maximum Wind Pressure" for "Indian Daily Weather Report".
- .. In description of Fig. 25 delete "to" before "H".
- .. 16. .. Last line of 1st para read "summarises" for "summarise".
- .. 20. .. 9th line from the bottom read "consecutive" for "consequent".
- .. 24. .. 16th line from the bottom insert "for" after "division".
- .. 29. .. 11th line from the bottom insert a semi-colon ( ; ) after "Fig. 9".
- .. 42. .. 3rd para, 5th line read "100° F" for "10".
- .. 45. .. Caption under Fig. 22 should read :—  
"Fig. 22—Maximum wind pressure".
- .. 53. .. In second line of the 3rd para, read  $\frac{1}{\lambda^n}$  ; instead of  $\frac{i}{n}$  .
- .. 54. .. Heading of Table 6 should read:—  
"Average values of actual number of hours of bright sunshine per day".
- .. 55. .. Heading of Table 7 should read:—  
"Percentage of solar radiation absorbed by different surfaces".
- .. 60. .. 4th line from the top read " $\sigma T$ " instead of " $\sigma T$ ".
- .. 62. .. 2nd line from the bottom read " $T_g$ " for "T".
- .. 65. .. 6th and 9th lines of para 2, read " $K (\theta_1 - \theta_2)$ " for " $K (\theta_1 \theta_2)$ ".
- .. 10th line of para 2, read  $\frac{d\theta_m}{dt}$  for  $\frac{d\theta}{dt}$  .
76. .. 1st line of para 3, read " $^{\circ}F$ " for "F".
- .. 84. .. 6th line from bottom read "Rohwer" for "Rohower".
- .. delete entire 3rd line from the bottom, viz., "charts.....writer";
- .. 2nd line from the bottom, delete "The"; last line of page, delete "in 1934 (2)".
- .. 87. .. 2nd line of 3rd para, insert the reference number "(2)" after "Raman and Satakopan".
- .. 88. .. Transpose 3rd and 2nd lines from the bottom so as to read :—  
"Transpiration over the Deccan, with rapidly decreasing values as one moves away in different directions therefrom; the secondary high potential over South-east Madras is also brought out."
- .. 108. .. 2nd line of para 3 after the words "first instance" replace comma (,) by semi-colon ( ; ).
- .. 116. .. 14th line from the bottom, for "number of plans" read "number of plants".
- .. 117. .. 15th line from the bottom, for "in the two clumps at eighter end" read "in the two clumps at either end".

## CHAPTER I

# WEATHER IN RELATION TO LONG TERM AS WELL AS SHORT TERM PLANNING OF AGRICULTURE : WEATHER RISKS : THE NEW WEATHER SERVICE FOR THE FARMER

## INTRODUCTION

In India, with her teeming millions, the Food Problem always assumes the highest priority. Agriculture has been and must continue to be our major industry. As is well known, the success of Indian agriculture depends mainly on the monsoon rains. We have reliable weather records only of about 75 years. As judged by these records, what is the dependability of rainfall in different parts of this vast sub-continent and what are the chances of success of agriculture in different parts of the country? How often in a century is the monsoon rainfall so conspicuously in excess (flood) or in deficit (drought) as to cause widespread havoc and failure of crops? Besides the vagaries of the monsoon, what are the other major weather risks to agriculture? These long-term aspects must carefully be considered if we are to plan our future agricultural development on sound lines.

## PHYSICAL AND CLIMATIC FEATURES

Figs. 1 and 2 show the distribution of the mountain and river systems and of the annual rainfall in India. The areas of very heavy rainfall are to the windward side of the Western Ghats, the hills of Assam, and the Himalayan barrier. These are the water-sheds from which originate the major river-systems of the country. Elsewhere, in the plateau of the Deccan, the Gangetic plains of north India and the plains of south India, the effects of orography are less pronounced or are completely absent and the rainfall is only moderate. In the north-west, the Punjab, Rajputana, and the adjoining tracts to the north and west constitute the driest area of the country.

Table 1 gives the normal rainfall in different seasons of the year and during the year as a whole in the various sub-divisions of India. For our present purpose, the year may be divided into four seasons, *viz.*, winter from December to February; summer or pre-monsoon from March to May; monsoon from June to September; post-monsoon from October to November. In columns (2) to (5) the figures within brackets indicate the seasonal rainfall expressed as percentages of the annual rainfall.

India is truly the land of monsoons. With the exception of Kashmir, the N. W. Frontier Province and Baluchistan in the north and S. E. Madras in the south, a very large percentage of the annual rainfall over the country occurs during the south-west monsoon (June to September). In the extreme north, a good proportion of the annual rainfall is contributed by winter precipitation, while in S. E. Madras nearly half the annual rainfall occurs during the post or retreating monsoon period (*i.e.* after September).

TABLE 1. NORMAL SEASONAL RAINFALL IN THE 30 RAINFALL SUB-DIVISIONS\* OF INDIA (IN INCHES)

Sub-division	Winter :	Summer or		Monsoon :	Post-monsoon:	Full year
	December to February " %	March to May " %	pre-monsoon :	June to September " %	October to November " %	
Assam	2.38 (2.4)	25.06 (25.7)		64.26 (65.8)	5.96 (6.1)	97.66
Bengal	1.53 (2.0)	12.42 (16.5)		56.01 (74.5)	5.17 (6.9)	75.13
Orissa	1.82 (3.2)	5.62 (9.9)		44.49 (78.2)	4.98 (8.8)	56.91
Chota Nagpur	2.57 (5.0)	3.64 (7.1)		42.71 (83.4)	2.26 (4.4)	51.18
Bihar	1.41 (2.9)	3.30 (6.8)		40.96 (85.0)	2.54 (5.3)	48.21
U. P. East	1.53 (3.9)	1.12 (2.9)		34.44 (88.0)	2.04 (5.2)	39.13
U. P. West	2.27 (6.0)	1.36 (3.6)		32.98 (87.8)	0.97 (2.6)	37.58
Punjab E. & N.	2.76 (11.9)	1.89 (8.1)		18.23 (78.4)	0.37 (1.6)	23.25
Punjab S.W.	1.28 (13.7)	1.36 (14.5)		6.58 (70.4)	0.13 (1.4)	9.35
Kashmir	9.12 (22.1)	9.09 (22.0)		22.19 (53.7)	0.94 (2.3)	41.34
N.W.F.P.	3.36 (20.0)	4.18 (24.9)		8.65 (51.5)	0.62 (3.7)	16.81
Baluchistan	3.50 (45.6)	2.03 (26.4)		1.89 (24.6)	0.26 (3.4)	7.68
Sind	0.67 (10.4)	0.41 (6.4)		5.28 (82.4)	0.08 (1.2)	6.44
Rajputana W.	0.62 (4.8)	0.56 (4.3)		11.74 (90.0)	0.12 (0.9)	13.04
Rajputana E.	0.96 (3.8)	0.78 (3.1)		22.91 (90.9)	0.55 (2.2)	25.20
Gujarat	0.22 (0.7)	0.24 (0.7)		31.46 (96.2)	0.77 (2.4)	32.69
C. India West	0.85 (2.5)	0.47 (1.4)		31.56 (93.8)	0.75 (2.2)	33.63
C. India East	1.44 (3.7)	0.79 (2.0)		35.05 (90.9)	1.30 (3.4)	38.58
Berar	1.01 (3.1)	0.96 (3.0)		28.10 (87.4)	2.07 (6.4)	32.14
C. P. West	1.47 (3.2)	1.14 (2.5)		41.04 (90.4)	1.76 (3.9)	45.41
C. P. East	1.58 (3.0)	2.10 (4.0)		46.37 (89.1)	1.99 (3.8)	52.04
Konkan	0.28 (0.3)	1.85 (1.7)		102.45 (93.7)	4.75 (4.3)	109.33
Bombay-Deccan	0.51 (1.7)	2.13 (6.9)		24.41 (79.1)	3.82 (12.4)	30.87
Hyderabad N.	0.67 (1.9)	1.53 (4.4)		29.51 (84.5)	3.20 (9.2)	34.91
Hyderabad S.	0.57 (1.9)	2.10 (7.0)		23.38 (78.1)	3.88 (13.0)	29.93
Mysore	0.73 (2.0)	5.47 (15.2)		22.27 (61.8)	7.54 (20.9)	36.01
Malabar	2.73 (2.6)	12.61 (12.2)		71.47 (68.9)	16.93 (16.3)	103.74
Madras S. E.	4.76 (13.6)	4.53 (12.9)		12.01 (34.2)	13.80 (39.3)	35.10
Madras-Deccan	0.74 (3.0)	2.42 (9.9)		15.27 (62.3)	0.09 (24.8)	24.52
Madras Coast North	1.69 (4.2)	3.44 (8.9)		25.03 (62.3)	10.00 (24.9)	40.16

## THE MONSOON

With the advance of summer, associated with the 'northing' of the sun, insolation increases rapidly over the higher latitudes, so that by the end of May, the region of highest air temperature and lowest atmospheric pressure lies over north-west India and the adjoining areas of Pakistan, Afghanistan, Persia, and Central Asia. This low pressure system takes over control of the air currents over Asia, so that the south-east trade winds from south of the equator are diverted into the Arabian Sea and the Bay of Bengal, and appear suddenly over the West Coasts of India and Burma respectively as the south-west monsoon. The Arabian Sea branch of the south-west monsoon, while crossing the Western Ghats, gives copious precipitation over that region, and continues to flow eastwards across the Deccan and central parts of the country, meeting the Bay branch of the monsoon along the trough of low pressure which extends from Orissa to north-west India. The Bay branch is deflected by the Arakkan Yomas and turned in its course so as to skirt the northern side of the low pressure trough while moving along the submontane tracts to the south of the great Himalayan barrier.

\* (To make the fullest use of past records, in the form readily available, the names of the sub-divisions as well as the country as a whole refer to those of pre-partitioned India.)



FIG. 1. Relief map of India and neighbourhood

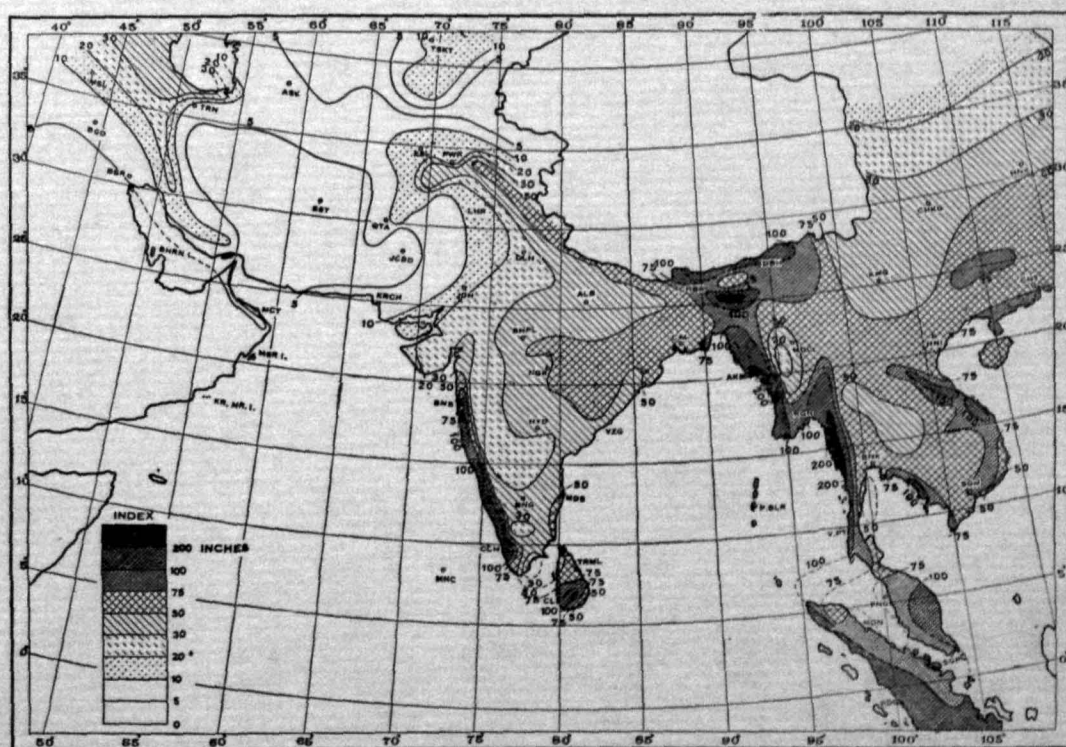


FIG. 2. Annual rainfall map of India and neighbourhood

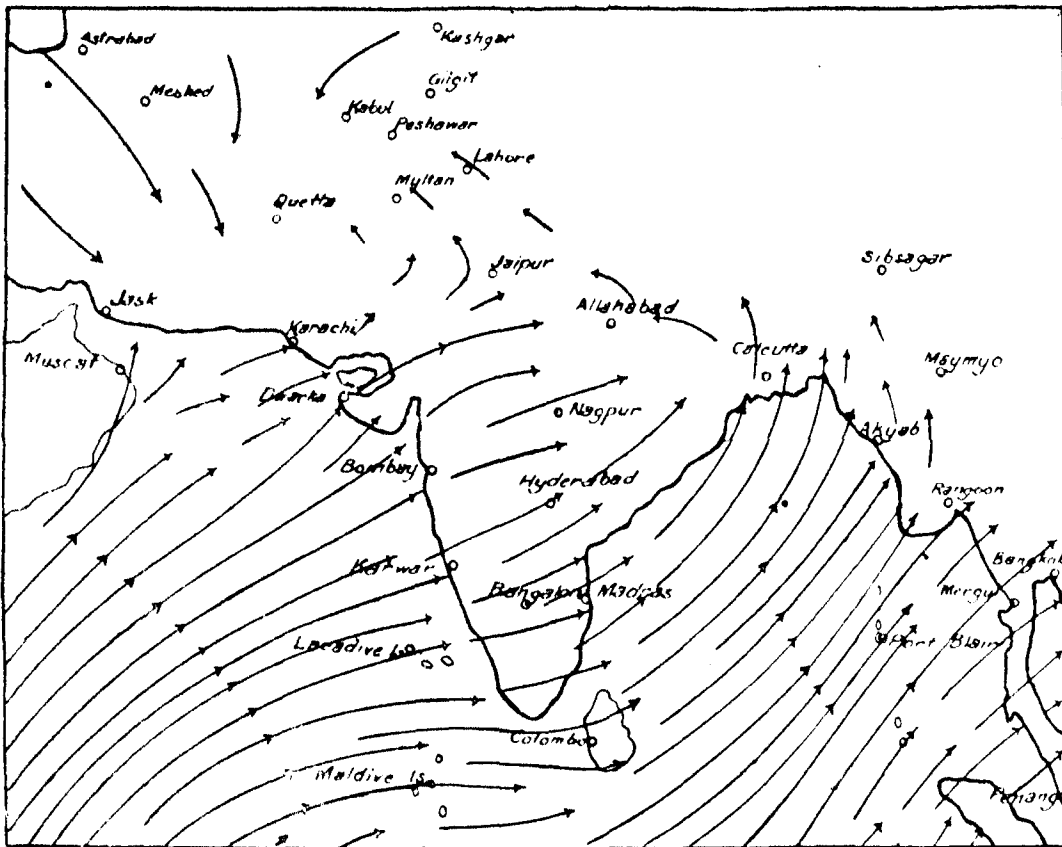


FIG. 3. Average wind currents ( July )

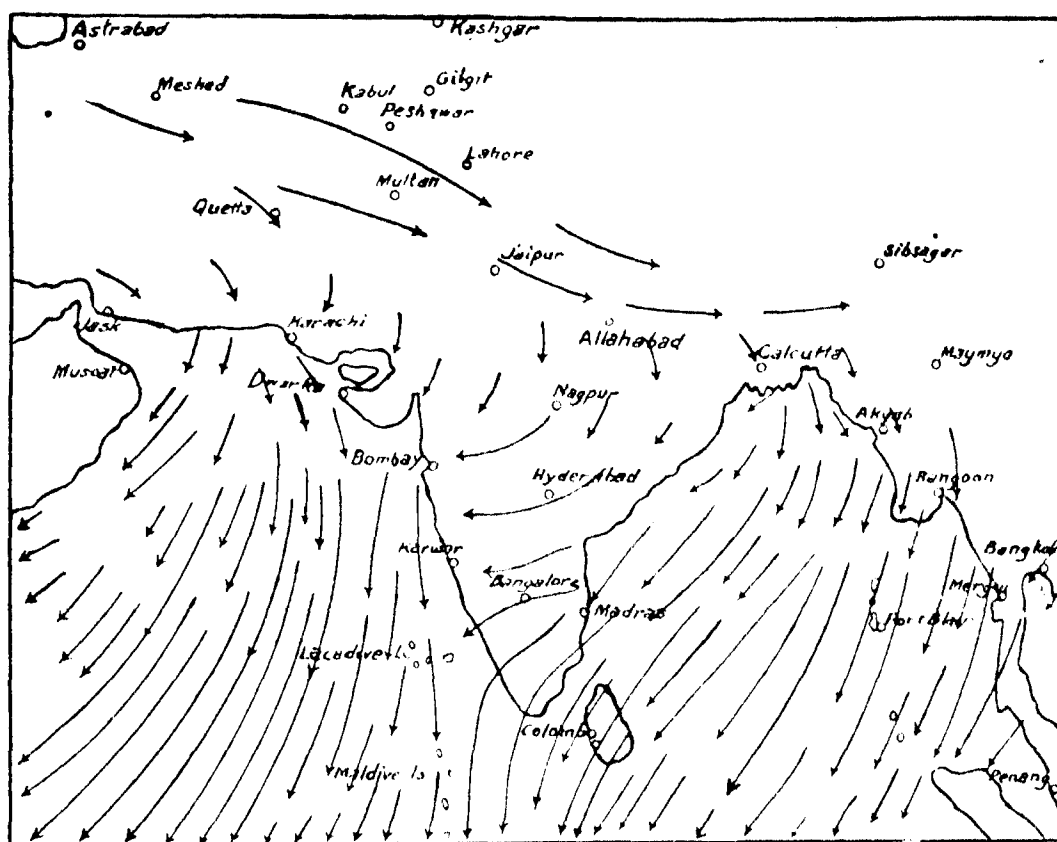


FIG. 4. Average wind currents ( January )

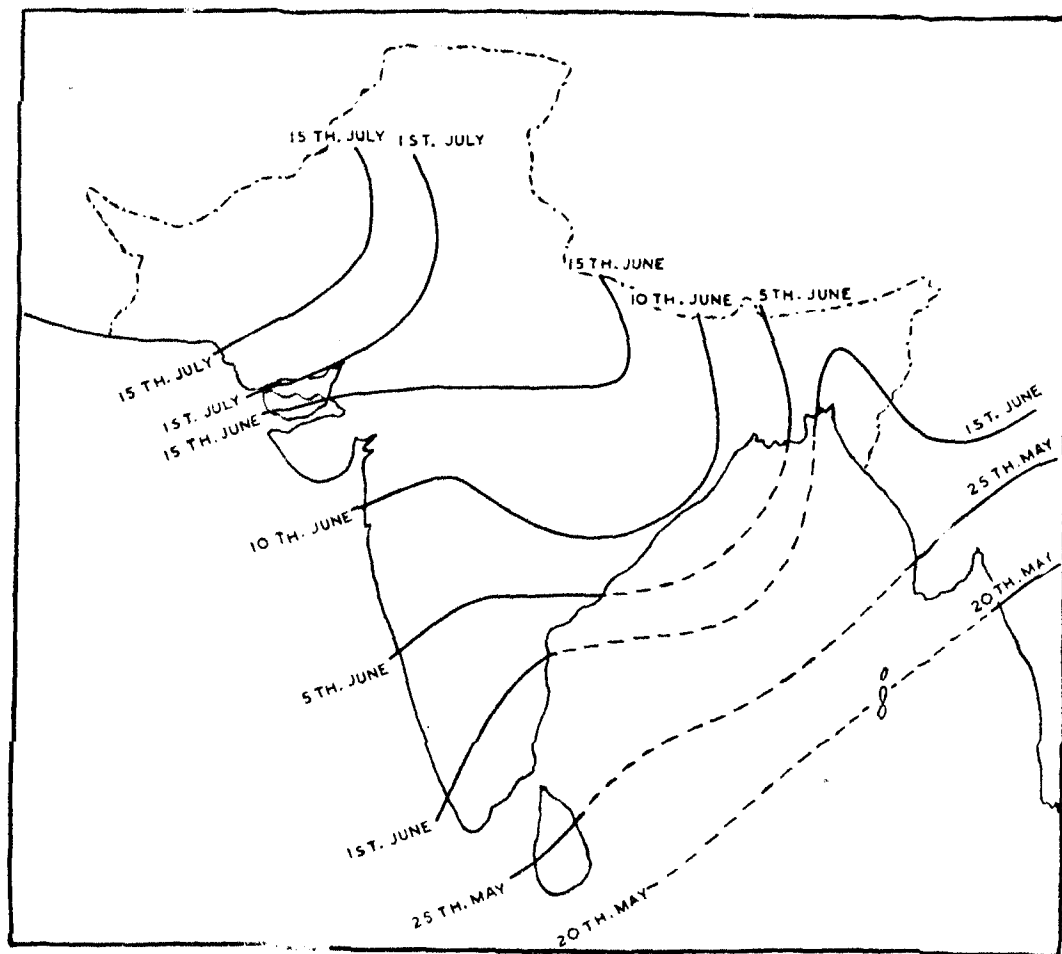


FIG. 5. Normal dates of onset of the S. W. Monsoon

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